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GEOLOGY, ENERGY AND MINERAL RESOURCES ASSESSMENT OF THE SOCORRO AREA, NEW MEXICO

BY

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GEOLOGY, ENERGY AND MINERAL RESOURCES ASSESSMENT OF THE SOCORRO AREA, NEW MEXICO

by

Jan Krason, Antoni Wodzicki and Susan K. Cruver

SUMMARY

The Socorro "Geological, Energy and Mineral (GEM) Resources Area" (GRA) lies within Socorro County, central New Mexico, and encompasses three Wilderness Study Areas (WSAs), namely:

NM-020-038 Sierra Las Canas
NM-020-035 Veranito
NM-020-040 Stallion

The GRA is underlain by Proterozoic granites and metamorphic rocks which are unconformably overlain by a transgressive Mississippian and Pennsylvanian shallow marine clastic and carbonate sequence, and Late Pennsylvanian and Permian regressive and transgressive sequence of continental and shallow marine redbeds and marine limestones. During the Mesozoic the area underwent erosion, deposition of Triassic continental redbeds and mild folding during the Laramide orogeny. From Late Eocene to Early Miocene it has been subjected to tectonism, intrusion of small epizonal plutons and voluminous volcanics erupted in part from several cauldrons. From 40 to 30 m.y.B.P. the volcanism was calc-alkaline and mainly of andesitic to quartz latitic composition; from 30 to 20 m.y.B.P. volcanism took on a bimodal character with calc-alkaline to high K calc-alkaline basaltic andesite and high silica rhyolite being the dominant phases. Rio Grande rifting was initiated during Early Miocene and was accompanied by bimodal volcanism and deposition of valley-fill sediments. Igneous and geothermal activity, and deformation continue to the present day.

Geological environments favorable for occurrence of mineral or energy resources include Permian redbeds, Cretaceous coal beds, Cenozoic hydrothermal systems and valley-fill sediments and active geothermal systems. The Permian Abo and Yeso Formations are moderately favorable for occurrence of stratabound copper and silver deposits. Extensive though thin and folded and faulted coal seams occur in the Cretaceous Mesaverde Group. Hydrothermal manganese and silver-gold veins occur in Tertiary Datil volcanics; and lead-barite-fluorite and uranium-vanadium occur along faults in Precambrian granite and Paleozoic limestones. Both of the above may be related to hydrothermal systems associated with cauldron subsidence. Valley-fill sediments of the Popotosa and Santa Fe Formations are possible hosts for stratabound uranium deposits provided suitable reductants are present at depth. Placer gold could be present in Cenozoic alluvium. The Socorro area contains numerous warm springs, is underlain by 4-5 km deep magma chambers and by reservoir and cap rocks, and is considered as highly favorable for geothermal energy development.

The Veranito WSA is underlain by Datil volcanics, Santa Fe Formation and Quaternary alluvium. It probably has a moderate favorability for hydrothermal precious metal and stratabound uranium deposits and a high favorability for geothermal energy. The Sierra Las Canas WSA is underlain by intensely faulted Permian sediments and lies close to the Rio Grande rift. It probably has a moderate favorability for stratabound copper-silver and hydrothermal lead-barite-fluorite deposits and for geothermal energy. The Stallion WSA is underlain by Permian sediments. It probably has a moderate favorability for stratabound copper-silver deposits.

It is recommended that a field petrographic and geochemical investigation be carried out on the WSAs in order to assess the favorability for mineral and energy resources more definitively.

INTRODUCTION

Purpose and Methodology

The need for "Geological, Energy and Minerals (GEM) Resources Assessment" of "Wilderness Study Areas" (WSA) has been recognized for some time by the Bureau of Land Management (BLM). The assessment is now being performed by various contractors for the BLM.

Wilderness Study Areas, widely scattered within the Sonoran Desert and Mexican Highlands and grouped into Region 5 by the BLM, are being studied and assessed by Geoexplorers International, Inc. The present report pertains to three WSAs in central New Mexico which have been grouped together into the Socorro Geological Energy and Minerals Resources Area (GRA).

The purpose of the present study is to assess the potential for locateable, leaseable and saleable resources within the GRA, and specifically within each of the WSAs. This assessment has been carried out through literature study of the geology, structure and economic geology of the GRA, and a consideration of the regional paleogeographic, plate tectonic and metallogenic setting of the GRA within the southern Cordillera. Thus, the assessment is not only based on data from the GRA itself, but also on metallogenic concepts within the regional paleogeographic and plate tectonic framework.

Location and Access

The Socorro Geological Resources Area lies in the south-central and southeastern parts of the Socorro 1:250,000 quadrangle and in the north-central and northeastern parts of the Tularosa 1:250,000 quadrangle, central New Mexico (fig. 1). The Atchison, Topeka and Santa Fe railway line runs from north to south in the western half of the GRA; and highways U.S.-60, U.S.-380, and I-25 traverse the southwestern quarter, southeastern quarter and western half of the area respectively. Unimproved, dry-weather roads provide reasonable access to the remaining parts of the GRA except in areas of steep topography near Polvadera Mountain, Socorro Mountain, and the Chupadera Mountains. The three Wilderness Study Areas located in the GRA include the Veranito, Stallion, and Sierra las Canas WSAs. All three WSAs are administered by the Socorro BLM district and have been designated by the BLM as follows:

NM-020-038	Sierra Las Canas	10,800 acres	(43.7 km^2)
NM-020-034	Veranito	7,450 acres	(30.1 km^2)
NM-020-040	Stallion	21,680 acres	(87.7 km^2)
	Total	39,930 acres	(161.5 km^2)

The WSAs and surround areas are shown in fig. 1.

PHYSIOGRAPHY

The Socorro GRA lies within and adjacent to the Rio Grande rift, a pronounced north-trending tectonic and topographic depression. The area is in the Mexican Highland section of the Basin and Range Province as defined by Fenneman (1928). To the north of the area, the Rio Grande rift forms the boundary between the Colorado Plateau to the west and the high plains to the east. Some 130 miles to the south, the rift loses its identity as a single physiographic feature and merges into the Basin and Range Province of southwestern New Mexico, Mexico and Arizona.

The GRA can be divided into three distinct physiographic terrains: the mountainous-to-hilly terrains in the far west, center and northeast, lowlands in the southeast and mid-west, and the Rio Grande floodplain in the mid-west (see figs. 1 and 3).

The mountainous-to-hilly terrains consist of the Chupadera uplift in the far west and the Joyita uplift in the center and northeast. Both are

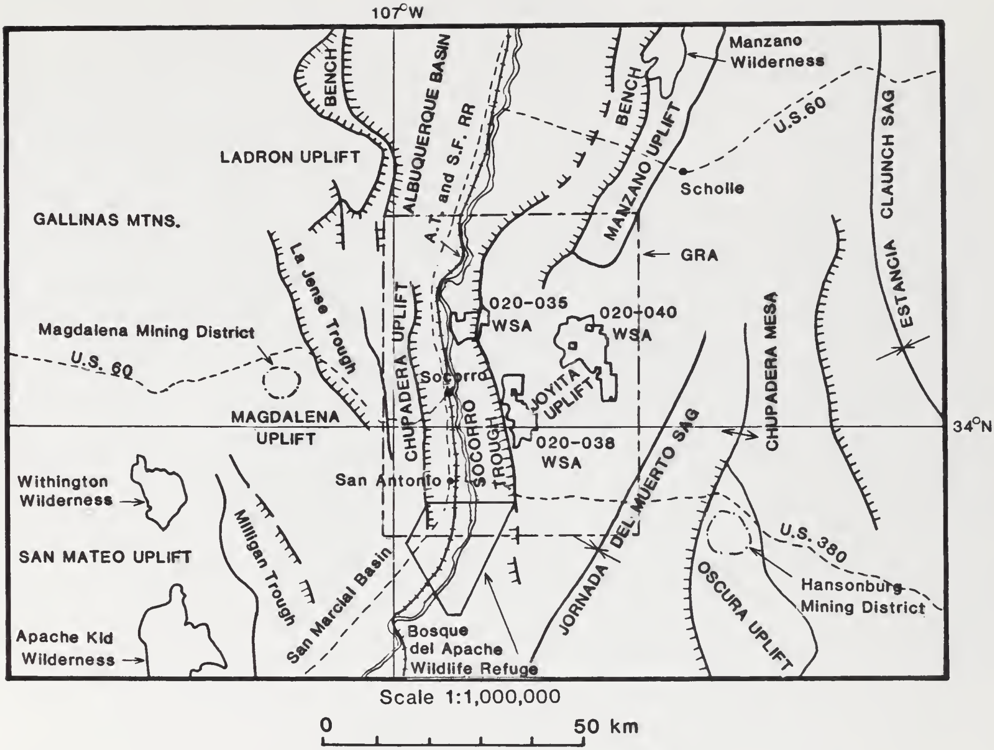


FIG.1. PHYSIOGRAPHIC MAP SHOWING THE LOCATION OF THE SOCORRO GRA AND THREE WSAs, PHYSIOGRAPHY AFTER KELLEY, 1979

fault block ranges which are complexly fautled and uplifted on their east and west margins respectively.

The lowland in the southeast is known as the Jornada del Muerto. It is a NNE-trending tectonic downwarp or sag (Kelley, 1979, p. 58) which is blanketed by an alluvial veneer covering a pediment surface. The mid-west lowland consists of the Socorro trough, a faulted tectonic depression filled with poorly-consolidated valley-fill deposits and forming part of the Rio Grande rift (Kelley, 1979, p. 58).

The floodplain of the Rio Grande River is 1-3 miles wide and is cut into poorly-consolidated older valley-fill deposits of the Rio Grande rift (Denny, 1940).

The Veranito WSA lies largely within the Socorro trough but extends onto the Rio Grande floodplain. The Stallion WSA lies within the Joyita uplift facing the Jornada del Muerto sag. The Sierra Las Canas WSA lies along the complexly-faulted western boundary of the Joyita uplift.

GEOLOGY

The lighology and stratigraphy, structural geology and tectonics, paleontology and geologic history of the Socorro GRA and surrounding central New Mexico are described in this section in order to facilitate the assessment of mineral potential within the area. The regional geologic setting is summarized in figure 2, and the detailed geology of the Socorro GRA is summarized in figure 3.

Lithostratigraphy - Rock Units

In central New Mexico, Precambrian crystalline basement is unconformably overlain by Late Paleozoic to Mesozoic shallow marine and continental sediments, mid-Tertiary arc volcanics, Late Tertiary valley-fill sediments within

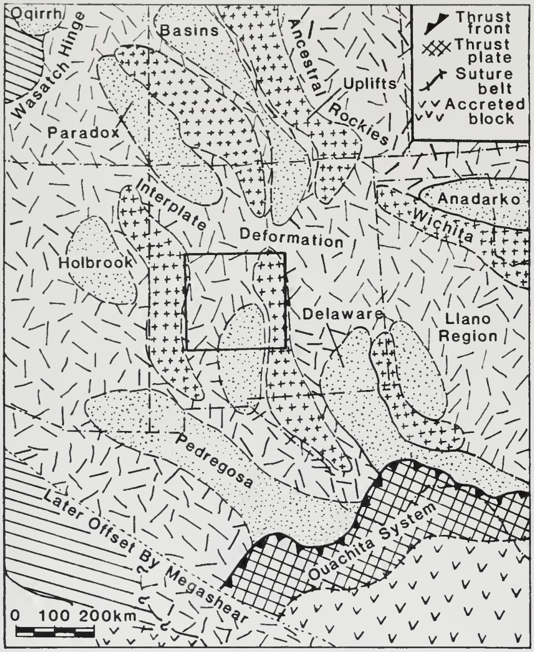
FIGURE 2: Paleotectonic maps of the southern Cordillera, New Mexico and adjoining areas, and map of mineral-deposit assemblage zones of the same area. Square outlines central New Mexico and approximates the location of figure 1.

A. Paleotectonic map, mid-Carboniferous to mid-Triassic (325-225 m.y.B.P.), featuring basins and uplifts of the Pennsylvanian and Early Permian. Dotted areas = basins; plusses (+) = uplifts.

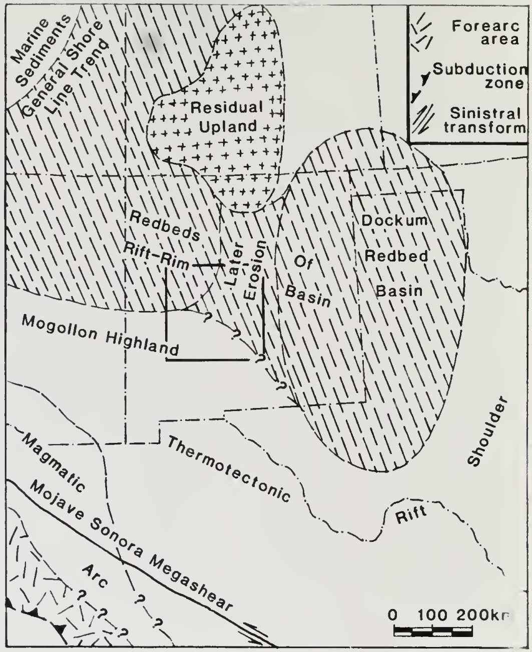
B. Paleotectonic map, mid-Triassic to mid-Late Jurassic (225-150 m.y.B.P.), showing redbed basins (dashed pattern) and thermo-tectonic rift shoulder. Rifted continental margin is immediately southeast of the area.

C. Paleotectonic map, latest Cretaceous to Recent time (75-0 m.y.B.P.), showing extent of Tertiary Laramide deformation and later Tertiary to present Rio Grande rift.

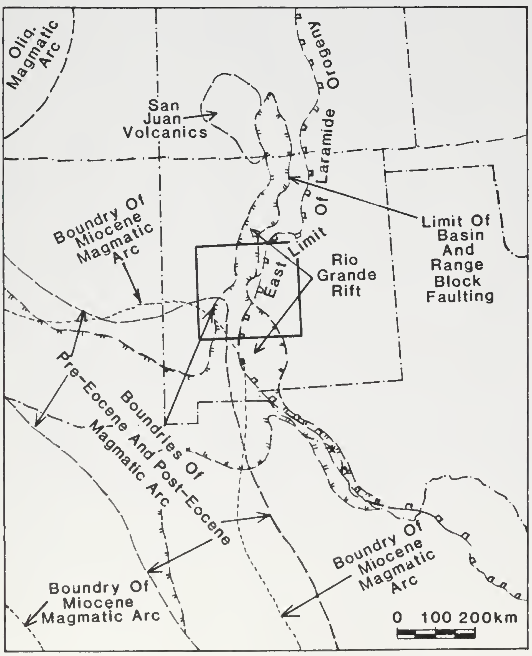
D. Mineral deposit assemblage zones. Light face dotted pattern = fluorite zone; bold face dotted pattern = molybdenum zone; v = copper-molybdenum zone. A, B, and C after Dickinson, 1981; D after Clark et al., 1982.


Oqirrh
Wasatch Hinge
Basins
Ancestral
Uplifts
Rockies
Paradox
Interplate
Deformation
Anadarko
Wichita
Holbrook
Delaware
Llano
Region
Pedregosa
Ouachita System
Later Offset By Megashear
Thrust front
Thrust plate
Suture belt
Accreted block
0 100 200km

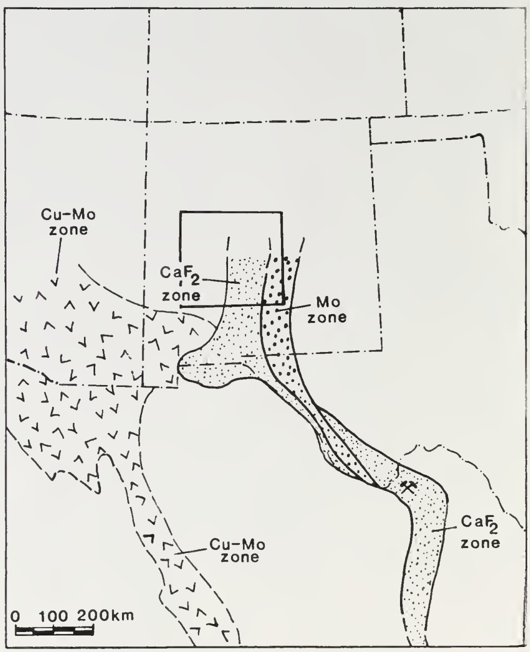
2a.


Marine Sediments
General Shore Line Trend
Residual Upland
Redbeds
Rift-Rim
Later Erosion
Of
Basin
Dockum
Redbed
Basin
Mogollon Highland
Magmatic
Thermotectonic
Rift
Shoulder
Mojave Sonora Megashear
Arc
Forearc area
Subduction zone
Sinistral transform
0 100 200km

2b.


Olig. Magmatic Arc
San Juan Volcanics
Laramide Orogeny
East Limit Of
Limit Of Basin And Range Block Faulting
Rio Grande Rift
Boundry Of Miocene Magmatic Arc
Pre-Eocene
Boundries Of Magmatic Arc
Pre-Eocene And Post-Eocene
Boundry Of Miocene Magmatic Arc
Boundry Of Miocene Magmatic Arc
0 100 200km

2c.


Cu-Mo zone
CaF_2 zone
Mo zone
Cu-Mo zone
CaF_2 zone
0 100 200km

2d.

FIG. 3. GEOLOGIC, ENERGY AND MINERAL RESOURCES MAP OF THE SOCORRO AREA, NEW MEXICO.

Scale
1 : 250,000
LEGEND: see enclosed

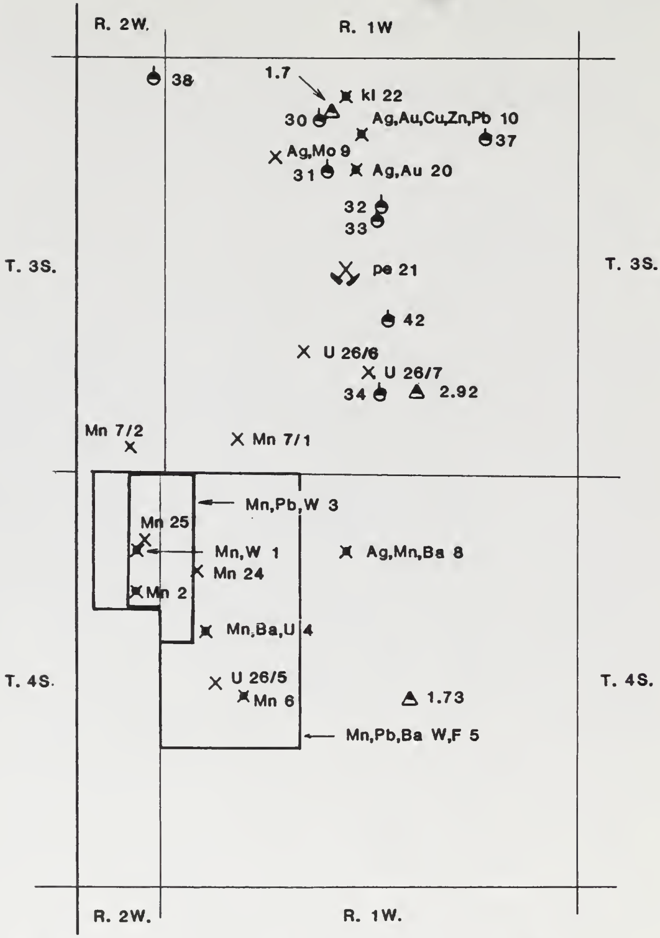


FIG. 3a　　DETAILED MAP FROM FIG. 3

Scale

1 : 125,000

ADDITIONAL EXPLANATION:

(ellipse)	Shallow magma body, see Fig. 3
△ 1.73	Thermal control point, number is the value in heat flow units (10^{-6} Cal/cm^2/sec)
⌖ 3584	Number indicates depth in feet, see Fig. 3
X U 26/6	Prospect's number corresponding in the text

Figure 4. **LEGEND**

FOR

GEOLOGIC, ENERGY AND MINERAL RESOURCES MAPS

Scale of all maps is 1:250,000 or as otherwise indicated.

LITHOSTRATIGRAPHY

After C.H. Dane and G.O. Bachman, 1965

QUATERNARY	HOLOCENE	Qal	ALLUVIUM – Mainly in flood plains
		Qab	ALLUVIUM – bolson deposits and other surficial deposits
	PLEISTOCENE	Qb	BASALT FLOWS
TERTIARY	PLIOCENE	QTp	PEDIMENT – terrace and other deposits of sand, gravel and caliche
	MIOCENE	QTs	SANTA FE GROUP – conglomerate, sandstone, mudstone, playa deposits and tuff QTsb – basaltic flows QTsr – rhyolite flows and tuffs
		Tpt	POPOTOSA FORMATION – gravel, tuffaceous sandstone, siltstone, gypsum
	OLIGOCENE	Tdr, Td	DATIL FORMATION Td – undivided Tdr – welded and crystal rhyolite tuffs, flows and breccias
	EOCENE	Tbc	BACA FORMATION – conglomerate, sandstone and clay
		TKi	INTRUSIVE ROCKS OF VARIOUS AGES – stocks, laccoliths, dikes, sills
CRETACEOUS	UPPER	K	CRETACEOUS ROCKS – undivided
		Kmv	MESAVERDE GROUP – conglomerate, sandstone, shale, siltstone, coal
		Km	MANCOS FORMATION – shale, coal, sandstone, limestone
	LOWER	Kd	DAKOTA SANDSTONE – includes glauconitic shale

TRIASSIC		TR	DOCKUM FORMATION – red siltstone, shale, conglomerate, sandstone
PERMIAN	GUADALUPE	Psa	SAN ANDRES LIMESTONE – includes some sandstone and gypsum lenses
	LEONARD	Pg	GLORIETA SANDSTONE – quartz sandstone
		Py	YESO FORMATION – sandstone, gypsum, limestone, siltstone, shale (light red)
	WOLFCAMP	Pa	ABO SANDSTONE – includes limestone pebble conglomerate, limestone, shale and siltstone (dark red)
PENNSYLVANIAN – MISSISSIPPIAN		IPm	MADERA LIMESTONE – includes sandstone, siltstone and shale
		IPms	MADERA LIMESTONE and SANDIA FORMATION Madera limestone as described above Sandia Formation – sandstone, coal, shale, limestone
PRECAMBRIAN		p€	Quartz monzonite of the Tajo pluton

SPECIAL SYMBOLS

OF STRUCTURAL FEATURES

After U.S. Geological Survey

Contact – Dashed where approximately located; short dashed where inferred; dotted where concealed

45

Contact – Showing dip; well exposed at triangle

Fault – Dashed where approximately located; short dashed where inferred; dotted where concealed

20

Fault, showing dip – Ball and bar on downthrown side

Normal fault – Hachured on downthrown side

Fault – Showing relative horizontal movement

Thrust fault – Sawteeth on upper plate

Anticline – Showing direction of plunge; dashed where approximately located; dotted where concealed

Asymmetric anticline – Short arrow indicates steeper limb

Overturned anticline – Showing direction of dip of limbs

Syncline – Showing direction of plunge; dashed where approximately located; dotted where concealed

Asymmetric syncline – Short arrow indicates steeper limb

Overturned syncline – Showing direction of dip of limbs

Monocline – Showing direction of plunge of axis

20 Minor anticline – Showing plunge of axis

60 Minor syncline – Showing plunge of axis

Strike and dip of beds – Ball indicates top of beds known from sedimentary structures

70 Inclined   Horizontal

Vertical   40 Overturned

Strike and dip of foliation

20 Inclined   Vertical   Horizontal

Strike and dip of cleavage

15 Inclined   Vertical   Horizontal

Bearing and plunge of lineation

15 Inclined   Vertical   Horizontal

Strike and dip of joints

40 Inclined   Vertical   Horizontal

Note: planar symbols (strike and dip of beds, foliation or schistosity, and cleavage) may be combined with linear symbols to record data observed at same locality by superimposed symbols at point of observation. Coexisting planar symbols are shown intersecting at point of observation.

SPECIAL SYMBOLS

FOR ENERGY AND MINERAL RESOURCES

KNOWN DEPOSITS AND OCCURRENCES

- O Oil field
- G Gas field
- Os Oil shale
- C Coal deposit
- C Coal occurrence
- Mineral orebody - as specified with symbol
- Mineral deposit - as specified with symbol
- Mineral occurrence - as specified with symbol
- Mineral district (Fig.= inserted map)

EXPLORATION AND/OR MINING ACTIVITY

MINERALS AND COAL

- Mineral deposit, mine or prospect with recorded prod.
- Prospect or mine with no recorded production
- Accessible adit, or tunnel
- Inaccessible adit, or tunnel
- Vertical shaft
- Inclined shaft
- Active open pit, or quarry
- Inactive open pit, or quarry
- Active gravel or clay (cl) pit
- Inactive gravel or clay (cl) pit
- Exploration hole with data available
- Exploration hole without data
- Mining district (Fig.= inserted map)

PETROLEUM

- Oil well
- Oil and gas well
- Gas well
- Show of gas
- Show of oil
- Show of oil and gas
- Shut-in well
- CO_2- or He-helium- rich well
- Dry well - abandoned

GROUND WATER

- Water well of special importance
- Water well of high yield
- Flowing water well
- Brine
- Mineral water
- Thermal water
- Radioactive water
- Thermal point

ENERGY RESOURCES

O	Oil
G	Gas
Os	Oil shale
Ot	Tar sands
C	Coal
Cb	Lignite (brown coal)
Cp	Peat
U	Uranium
Th	Thorium
Gt	Geothermal

MINERAL RESOURCES

METALS

Al Aluminum
Sb Antimony
As Arsenic
Be Beryllium
Bi Bismuth
Cd Cadmium
Cr Chromium
Cs Cesium
Co Cobalt
Cu Copper
Ga Gallium
Ge Germanium
Au Gold
Fe Iron
Pb Lead
Li Lithium
Mn Manganese
Hg Mercury
Mo Molybdenum
Ni Nickel
Nb Niobium or Columbium
Pt Platinum group
RE Rare earth
Re Rhenium
Sc Scandium
Ag Silver
Te Tellurium
Tl Thallium
Sn Tin
Ti Titanium
W Tungsten
V Vanadium
Zn Zinc
Zr Zirconium and
Hf Hafnium

NONMETALS - INDUSTRIAL MINERALS

ab Abrasives
al Alum
as Asbestos
Ba Barite
be Bentonite
ca Calcite
cl Clay

Construction materials :

cs Crushed stone
la Lightweight aggregates, includ.:
pm Pumice and volcanic cinders
pe Perlite
ec Expanded clay, shale, slate
vm Vermiculite
sg Sand and gravel
cr Cement raw materials
bs Building stones
ll Lime

dl Diatomite

Nonmarine and marine evaporites and brines

pt Potash
na Salt - mainly halite
gy Gypsum and anhydrite
nc Sodium carbonate or sulfate
bn Boron minerals
ni Nitrates
Sr Strontium
Br Bromine
cc Calcium chloride
mg Magnesium compounds

fs Feldspar
F Fluorite (fluorspar)
gs Gem stones
ge Graphite
He Helium
kl Kaolin
ky Kyanite and related minerals
ls Limestone
lm Lithium minerals

mg Magnesian refractories
mi Mica
ph Phosphate
pi Pigment and fillers
qz Quartz crystals
si Silica sand
S Sulfur
tc Talc
ze Zeolites
hm Humate

SPECIAL GEOLOGICAL FEATURES

POINT OF SPECIAL GEOLOGIC INTEREST

m	Mineral occurrence	s	Structural, bedding, foliation, etc.,	u	Radioactive spring
f	Fossil locality	b	Brecciation, shear zone, etc.,	g	Thermal spring
v	Volcanic phenomenon	y	High yield spring	a	Extensive rock alteration
t	Stratigraphic sequence	p	Spring with mineral water	r	Lithologic type locality

FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE FOR MINERAL RESOURCES

FAVORABILITY:

1A - Undefined

1 - Not favorable - combine with either B, C, or D

2 - Low
3 - Moderate
4 - High

(2, 3, 4: combine with either A, B, C, or D)

LEVEL OF CONFIDENCE:

A - Insufficient data

B - Indirect evidence

C - Direct evidence

D - Abundant direct and indirect evidence the Rio Grande rift and Late Tertiary to Quaternary bimodal volcanics. The GRA lies close to the eastern limit of the region affected by the Laramide orogeny and has been tectonically active since the early Miocene.

Precambrian Rocks

The Precambrian rocks of central and south-central New Mexico have been intensely studied by Condie and Budding (1979). They are within an ENE-trending belt that extends from southwest New Mexico to Illinois and are 1.2-1.65 b.y. old. In central New Mexico the Precambrian rocks consist mainly of granitic plutons (70%) which intrude metamorphic rocks (30%). The metamorphic grade ranges from lower greenschist to amphibolite facies. In decreasing order of abundance the metamorphic rocks consist of phyllite and quartz-mica schist, quartzite and arkosite, mafic meta-igneous rocks, siliceous meta-igneous rocks and gneisses. According to Condie and Budding (1979), this sequence is similar to associations formed in modern continental rift systems; but according to Dickinson (1981), the voluminous granites, calc-alkaline volcanics and widespread metamorphic belts suggest a convergent environment.

In the Socorro GRA small exposures of Precambrian rocks occur along the western margin of the Joyita hills east of Socorro and in the Lemitar Mountains (fig. 3). The exposures lie along the uplifted eastern sides of faults (Condie and Budding, 1979) probably associated with the eastern margin of the Socorro trough. The rocks consist of Precambrian medium- to coarse-grained quartz monzonite (Foster and Stipp, 1961) comprising part of the Tajo pluton (Condie and Budding, 1979).

Mississippian

Mississippian sediments are found in the northern Magdalena Mountains (Titley, 1961) and in the southern Chupadera Mountains (Bachman and Stotelmeyer, 1967). They are exposed in the Lemitar Mountains of the Socorro GRA, and could underlie parts of the Chupadera Mountains. According to Armstrong (1958), the Caloso and Kelly Formations comprise the Mississippian in central New Mexico. The Caloso is about 30 feet thick and consists of a basal arkosic sandstone overlain by a dark algal limestone. It rests unconformably on Precambrian basement. The Kelly Formation is up to 70 feet thick and consists of light tan to gray, medium-grained limestone. In the Magdalena district it is the host rock for the replacement Pb-Zn-Ag deposits (Titley, 1961). It disconformably overlies the Caloso Formation or Precambrian basement.

Pennsylvanian

Pennsylvanian sediments crop out in the foothills to the west of the Rio Grande and in the west-central and north-central parts of the Joyita uplift (fig. 3). They crop out in the northern part of the Sierra Las Canas WSA. Kottlowski (1960) has studied Pennsylvanian sections of central New Mexico where it is divided into the Sandia and Madera Formations fo the Magdalena Group.

The Sandia Formation consists of pebbly to fine-grained arkosic sands, coal laminae, black and green shales and dark arenaceous limestone. Calcareous lenses contain abundant brachiopods. In the Joyita hills it is up to 150 feet thick, but it thins to the southeast, and, in the northern Oscura Mountains' Hansonburg mining district, it is 15-40 feet thick (Kottlowski, 1953; Bachman, 1968). In the Socorro GRA the Sandia rests unconformably on Precambrian basement, but elsewhere it rests unconformably on the Kelly Formation.

The Madera Formation is between 1,400 and 1,850 feet thick. It is divided into three members: the Gray Mesa member which is 800-900 feet thick and consists of a gray cherty limestone with fusulinids and brachiopods; the Astrado member which is 750 feet thick and consists of siltstone and arkosic sandstone; and the Red Tanks member which is 200-300 feet thick and consists of red and buff sandstone, conglomerate, siltstone, shale, and limestone and arkosic sandstone. The Madera Formation rests conformably on the Sandia Formation.

Permian

Permian sediments crop out throughout the Joyita hills and are present in the Sierra Las Canas and Stallion WSAs (fig. 3). The Permian rocks of central New Mexico have been studied by Kottlowski et al. (1956) and Kottlowski (1963), and have been divided into the Bursum, Abo, Yeso and San Andres Formations.

The Bursum Formation crops out locally in the Socorro area (P.F. King, pers. comm.) and is present to the east in the Oscura Mountains (Bachman, 1968) and may underlie the eastern part of the GRA. It consists of dark red to reddish brown conglomerate, arkose and shale with interbeds of a brownish gray marine limestone containing colonial algae. It is 450 feet thick and grades downward into the Madera Formation.

The Abo Formation is widespread in the Joyita hills, to the east of the Oscura Mountains, and crops out in the northern part of the Sierra Las Canas WSA (fig. 3). It consists of a basal limestone pebble conglomerate and silty limestone, dark red arkosic sandstone and reddish shale and siltstone. Cobbles in the conglomeratic beds contain granite, limestone and, in the Oscura Mountains, quartzite and rhyolite (Bachman, 1968). The Abo is mainly terrestrial and is 300-450 feet thick. It rests unconformably on the Bursum in the Oscura Mountains, and conformably on the Madera Formation in the Joyita hills.

The Yeso Formation is widespread in the Joyita hills, and the Oscura Mountains to the east, and it crops out extensively in the Sierra las Canas and Stallion WSAs (fig. 3). It is mainly shallow marine-lagoonal and consists of orange to light red sandstones, evaporitic gypsum-bearing beds up to 150 feet thick, orange to light gray sandstone, arenaceous to argillaceous limestone, siltstone and shale. The Yeso is 750 feet thick at the type locality to the northeast of Socorro and it is about 250 feet thick in the Oscura Mountains to the east (Bachman, 1968). It grades into the underlying Abo Formation from which it is distinguished mainly by a change in color from dark to light red. The boundary also represents a change from dominantly terrestrial conditions in the Abo to mainly lagoonal in the Yeso.

The Glorieta sandstone is present in the Joyita hills and crops out in the southwestern and northeastern WSAs (fig. 3). It is a well-sorted, light gray quartzose sandstone which occurs as lenses up to 200 feet thick near the boundary between the Yeso Formation and the overlying San Andres Formation and is probably part of the latter.

The San Andres Formation is widespread in the Joyita hills and crops out in the Sierra las Canas and Stallion WSAs (fig. 3). It consists of gray, medium-bedded to massive fossiliferous limestone, containing cephalopods and brachiopods near Socorro. The basal part is interbedded with gypsum and lenses of sandstone. It is about 600 feet thick and grades into the underlying Yeso Formation.

The Permian sediments were deposited in a basin into which sediment was fed from the Pedernal uplift to the east and southeast and from the Burro-Zuni uplift to the west and northwest (fig. 2) (Dickinson, 1981).

Triassic

The Triassic Dockum Formation crops out in the Joyita hills and in the Jornada del Muerto sag, and also in the Sierra las Canas and Stallion WSAs (fig. 3). It consists of pale reddish calcareous siltstone and shale with local lenses of pebble conglomerate and sandstone up to 50 feet thick. The unit varies in thickness from 50-500 feet (Kottlowski, 1963) and rests unconformably on the San Andres Formation. The Dockum is terrestrial and Hilpert (1969) suggests it is similar to the Shinarump member of the Chinle Formation which, in northwestern New Mexico, is host to important stratabound uranium deposits. Sediments of the Dockum Formation were derived from the Mogollon Highlands to the south (Dickinson, 1981).

Cretaceous

Cretaceous sediments crop out in the western Joyita hills and in the Jornado del Muerto sag (fig. 3). They consist of the Dakota and Mancos Formations and the Mesaverde Group, described by Kottlowski (1963) and Kottlowski et al. (1956).

The Dakota Formation consists mainly of gray-brown quartz sandstone with some interbedded gray to green, locally glauconitic shale. Near the base are fluvial channel deposits including conglomerate lenses, crossbedded sandstone and carbonaceous shale. The presence of glauconite suggests that the Dakota is partly marine. Near Socorro it is about 20 feet thick and rests unconformably on the Dockum Formation.

The Mancos Formation consists of gray carbonaceous shale with local coal lenses, minor fine, locally calcareous and gypsiferous, sandstone, and limestone. It is marine and contains abundant plant fossils, cephalopods, pelecypods, ostrea and brachiopods. It is up to 295 feet thick and conformably overlies the Dakota.

The Mesaverde Group consists of an olive-brown basal conglomerate overlain by marine sandstone and sandy calcareous shale siltstone which, in turn are overlain by non-marine mudstones, shales and coal. The formation is about 900 feet thick and it conformably overlies the Mancos.

Early Tertiary

The Baca Formation, of probable Eocene age, crops out near the Rio Grande rift northeast of Socorro and near the Jornada del Muerto sag in the southeastern part of the GRA (fig. 3). According to Hilpert (1969) it is about 1,000 feet thick and consists of conglomerate, red and white sandstone and red clay. The conglomerate contains pebbles to boulders of Precambrian and Paleozoic provenance. It rests unconformably on a bevelled surface formed on the underlying Paleozoic and Mesozoic sedimentary rocks.

Mid-Tertiary

Late Eocene to Early Miocene volcanic rocks of the Datil Formation crop out over much of the Chupadera Mountains and locally in the Joyita hills (fig. 3). The eastern third of the Veranito WSA and the eastern margin of the Sierra las Canas WSA are underlain by the Datil Formation. The volcanism lasted between about 40 and 20 m.y. ago (Burchfiel, 1979) and peaked about 30 to 25 m.y. ago (Lipman, 1981). According to Elston and Bornhorst (1979), between 40 and 32 m.y. ago and the volcanism was related to subduction of the Farallon plate and consisted of calc-alkaline andesite, quartz latite and rhyolite; activity becoming more felsic with time. These rocks may possibly be correlated with the calc-alkaline and potassic calc-alkaline rocks described by Clark et al. (1982) to the south of the Socorro area. In the central New Mexico area, voluminous quartz latitic ash flow deposits, tuff breccias and flows were erupted from cauldrons (Elston, 1978), into which epizonal monzonite and quartz monzonite plutons were later intruded. During this time the North Baldy cauldron was active (Elston, 1978).

Between 32 and 20 m.y. ago the Pacific plate collided with the American plate, the San Andreas fault was initiated, subduction slowed down and back arc, bimodal calc-alkaline basaltic andesite and high-silica rhyolite volcanism developed (Elston and Bornhorst, 1979). These rocks may possibly be correlated with the Potassic calc-alkaline and alkaline volcanics described by Clark et al. (1982) to the south of the Socorro area. In central New Mexico, voluminous high silica rhyolitic ash flow deposits, tuff breccias and flows were erupted from cauldrons (Elston, 1978), into which later epizonal plutons were intruded. During this time the Nogal Canyon, Mt. Withington, Sawmill Canyon, Socorro and Hop Canyon cauldrons were active (Elston, 1978).

Volcanic rocks close to the cauldrons have been extensively hydrothermally altered and strongly enriched in potassium (Chapin et al., 1978). This was probably caused by ancient geothermal systems and may be associated with hydrothermal ore deposits.

The Veranito and Sierra las Canas WSAs lie close to the margin of the Socorro cauldron (see fig. 3). The Veranito WSA is probably entirely underlain by the Datil Formation.

Late Tertiary

During the Miocene and Pliocene, valley-fill sediments of the Popotosa and Santa Fe Formations were deposited along the Rio Grande rift, a major tectonic depression which extends into Colorado in the north and to the south merges into the Basin and Range Province. Coeval volcanism is also associated with the rifting. The Popotosa and Santa Fe Formations, together with minor volcanics, crop out along the Rio Grande (fig. 3). They have been described in the Albuquerque basin and Socorro trough by Denny (1940) and Kelley (1977).

The Popotosa Formation crops out only on the western margin of the Rio Grande rift. It is 3,000-5,000 feet thick and consists of lenses of gravel, red tuffaceous sandstone, red and gray siltstone and massive beds of gypsum with selenite (Denny, 1940). The gravels contain pebbles, cobbles and boulders of granite, schist, quartzite, sandstone and volcanics derived from Precambrian basement and Datil volcanics to the west. The sediments are alluvial fan deposits and playa deposits that lie unconformably on Datil volcanics and basement.

The Santa Fe Formation is at least 2,000 feet thick and crops out on both sides of the Rio Grande (fig. 3). It consists of conglomerate, pinkish, light olive and white sandstone, gray and brown mudstone, and locally tuffaceous playa deposits present in the center of the Socorro basin. The conglomerates contain boulders, cobbles and pebbles of granite, quartzite, schist and volcanics. Fossil mastodons and horse teeth indicate a Pliocene age. The Santa Fe Formation rests unconformably on Precambrian basement, on the Popotosa Formation and on Datil volcanics. The western two-thirds of the Veranito WSA overlies the Santa Fe Formation.

Volcanism associated with the Rio Grande rift commenced 21 m.y. ago and coincided with the growth of the San Andreas transform and intra-plate block faulting of the Basin and Range Province (Elston and Bornhorst, 1979). The volcanic rocks consist of olivine tholeite, basaltic andesite, alkali olivine basalt and lesser rhyolites (Balbridge, 1979). These volcanics are interbedded with the Santa Fe Formation and rest on Datil volcanics.

Quaternary

Quaternary deposits include basalt and unconcolidated sediment. The basalt caps some hills in the Joyita uplift and in the Chupadera Mountains (fig. 3) and represents a continuation of Rio Grande rift-related volcanism. Sediments include older terrace gravel deposits and present-day floodplain gravels of the Rio Grande.

Igneous activity is continuing to the present day. Recent work involving seismic refraction (Olsen et al., 1979), seismic reflection (Brown et al., 1979) and microearthquake studies (Sanford et al., 1979), have shown that a magma sill underlies the Albuquerque basin to the north of Socorro at a depth of 19-20 km and that several smaller magma chambers are present in the Socorro area at a depth of about 5 km (see fig. 3). This is important because the presence of these shallow magmas enhance the geothermal potential of the GRA. One of the magma chambers lies only a few miles from the Veranito and Sierra las Canas WSAs.

Structural Geology

The GRA lies within the North American craton, which during the Proterozoic had undergone two periods of deformation and granite intrusion (Condie and Budding, 1979). The area remained tectonically quiet until the Pennslvanian-Permian, at which time, possibly due to the Ouachita orogeny in the south, the region underwent warping (Dickinson, 1981).

During the Laramide orogeny, minor folding and thrusting took place (see fig. 2C) but this was not associated with any igneous activity in central New Mexico. During the Oligocene the dip of the Farallon plate beneath North America decreased to about 15° (Coney and Reynolds, 1977) and voluminous calc-alkaline volcanics were erupted from several cauldrons in central New Mexico (Elston, 1978; Elston and Bornhorst, 1979). These were undoubtedly associated with collapse structures and normal faults. The Sawmill Canyon and the Socorro cauldrons extend into the southwestern part of the GRA (fig. 3). The Veranito and Sierra las Canas WSAs lie within about five to ten miles of the cauldrons.

From early Miocene to the present has been a time of intense tectonic activity along, and close to, the Rio Grande rift (fig. 2C). Brown et al., (1979) have found evidence of faults with displacements of up to 4 km within the rift and Reilinger at al., (1979) have shown from repeated leveling measurements that parts of the Albuquerque basin are being uplifted at a rate of 0.5 cm per year. The crustal thickness beneath the Rio Grande rift has been found to be 35 km, compared to crustal thickness of 45 km and 55 km beneath the Colorado Plateau and Great Plains respectively (Keller et al., 1979). The thinning of the crust, bimodal volcanism and normal faulting are probably related to cessation of subduction following the growth of the San Andreas fault since the Miocene.

In the Socorro GRA close-spaced normal faults are present in the Joyita hills on the east flank of the Socorro trough. The normal faulting probably extends beneath the Santa Fe Formation within the Socorro trough. The Sierra las Canas WSA covers a particularly intensely faulted area.

The near coincidence of intense faulting, past igneous activity from cauldrons, and the presence of magma chambers within the crust in the Socorro area may, according to Chapin et al, 1978), be the result of the intersection of several lineaments in the Rio Grande vicinity. These may have weakened the crust sufficiently to allow upward migration of magmas through the crust and thus account for this localized igneous and tectonic activity.

Geological History and Paleogeographic Development

The geological history of the area is long and complex and only a brief synopsis is presented here. Excellent summaries of the main geological events that affected the Cordillera of New Mexico are given by Hilpert (1969), Burchfiel (1979), and Dickinson (1981). More detailed accounts are given by Condie and Budding (1979) for the Precambrian, Bachman (1968) for the Paleozoic, Kottlowski et al., (1956) and Kottlowski (1963) for the Paleozoic and Mesozoic, and Elston and Bornhorst (1979) for the mid-Tertiary to Quaternary.

The area lies within a 1.2-1.65 b.y. ENE-trending belt within the North American craton which is distance from a 1.65-1.9 b.y. belt to the northwest. It contains metasedimentary and both mafic and felsic meta-igneous rocks that have been folded twice, metamorphosed and intruded by granites.

The post-Precambrian geologic history can be summarized as follows:

1. Some time prior to the mid-Paleozoic, the area was uplifted and eroded to a peneplain.
2. Transgression took place during the Mississippian and Pennsylvanian. At this time the shallow marine clastic and carbonate sequence represented by the Caloso, Kelly, Sandia and lower Madera Formations was deposited.
3. During the Late Pennsylvanian and Early Permian, the Ouachita orogeny to the south caused in the Pedernal and Burro-Zuni uplifts and a gradual regression in the central New Mexico area (fig. 2A). The uplifts were the main sediment sources during the Late Pennsylvanian and Permian. During the regression, shallow marine limestone and red clastics of the upper Madera and Bursum Formations were deposited. The culmination of this regressive sequence is the Abo Formation which is a continental redbed sequence.
4. A marine transgression followed with deposition of shallow marine-lagoonal Yeso Formation which contains evaporites and redbeds, and the mainly carbonate San Andres Formation.
5. During the Triassic, the area was uplifted, bevelled and the continental redbed Dockum Formation was deposited (fig. 2B).

6. The area remained uplifted during the Jurassic and no sedimentation took place. During the Cretaceous, shallow marine sedimentation was followed by deposition of coal-bearing terrestrial beds of the Mesaverde Formation.
7. The Laramide orogeny barely affected central New Mexico and resulted in minor thrusting and folding (fig. 2C). This was followed by a prolonged erosion and bevelling of the surface.
8. From the latest Eocene to the present day followed a period of volcanism and tectonicm which can be divided into three phases:

   a. The first phase lasted from 40 to 30 m.y. During this time, the dip of the Benioff zone beneath the American plate decreased to less than 15^{o} and calc-alkaline, mainly andesitic and quartz latitic, volcanism took place. Voluminous quartz latitic ash flow deposits were erupted from cauldrons and small epizonal monzonite to quartz monzonite plutons were intruded.
   b. The second phase lasted from 30 to 20 m.y. At this time the Pacific plate collided with North America, the San Andreas fault was initiated and a modified back arc stage of volcanism took place as a result of the still active Farallon plate beneath the southern Cordillera. Volcanism took on a bimodal character with calc-alkaline to high potassium calc-alkaline basaltic andesite and high silica rhyolite being the dominant phases erupted. Extensive ash flow deposits of the high silica rhyolite

were erupted from cauldrons and epizonal plutons of quartz monzonite and granite were intruded.

c. From 20 m.y. to the present, intraplate normal faulting and bimodal volcanism has taken place and is probably associated with cessation of subduction and the growth of the San Andreas transform. During this time, the Rio Grande rift developed (fig. 2C) and was filled with valley-fill sediments.

9. Igneous activity and deformation have continued to the present day as evidenced by the presence of magma chambers beneath the Socorro area.

ENERGY AND MINERAL RESOURCES

The following are descriptions of known mineral deposits, prospects, occurrences, mineralized areas and thermal wells and other energy resources in the GRA. The following was derived largely from U.S. Geological Survey (1981-the CRIB File), and also from Clippinger (1949), Haigler and Sutherland (1965), McAnulty (1978), New Mexico Bureau of Mines and Mineral Resources (1965), Reiter and Smith (1977), Summers (1965), U.S. Geological Survey (1981), and other references quoted in the main body of this report. It represents a summary of knowledge available to the writers regarding individual mines and occurrences. Each entry is located on figure 3 or 3a and identified by a number given in the text.

Known Mineral Deposits, Mines or Prospects with Recorded Production

1. Tower Mining Company Deposit

Location:	33°58′50"N, 106°59′52"W NE-1/4 Sec. 12, T4S, R2W New Mexico Meridian
Commodities	Mn, W
Ore Materials	Psilomelane (?).
Description of Deposit:	Along shears, 2,000 feet in length. WO_3 up to 0.24%.

Geology: Mineralization is along faults and shear zones in rhyolites of the Tertiary Datil Formation.
Production: Total unknown; some production in the mid-1950s.

2. Gianera Deposit
   - Location: 30°58´28"N, 106°59´52"W; SE-1/4 Sec. 12, T4S, R2W
   - Commodity: Mn
   - Ore Material: Psilomelane
   - Description of Deposit: Veins in shear zone.
   - Geology: Mineralization is along shear zones in Tertiary rhyolite of the Datil Formation.
   - Production: Some production in mid-1950s; total unknown.

4. Red Hill Deposit includes Red Hill Extension
   - Location: 33°57´00"N, 106°59´00"W; NW-1/4 of NE-1/4 Sec. 19, T4S, R1W New Mexico Meridian
   - Commodities: Mn, Ba, U
   - Ore Materials: Psilomelane (?).
   - Description of Deposit: Shear zone deposit.
   - Geology: Mineralization is along shear zones in Tertiary rhyolite of the Datil Formation.
   - Production: WWI: 100 tons of 35% Mn concentrate. Production also in WWII: about 4,700 tons of 44-45% Mn 1944-1946. Concentrate also contains 12.3% BaO and 0.33% U_2O_3. Production also in mid-1950s.

5. Luis Lopez District
   - Location: 33°57´45"N, 106°58´27"W; Sec. 5, 6, 7, 8, 17, 18, 19 and 20, T4S, R1W and Sec. 1 and 12, T4S, R2W New Mexico Meridian
   - Commodities: Mn, Pb, Ba, W; Major product: Mn; Minor products: Pb, Ba
   - Ore Materials: Psilomelane, pyrolusite, coronadite, wad; barite, W-bearing coronadite, fluorite.
   - Description of Deposit: Irregularly shaped veins and shear zone mineralization (thin films, small veins and irregular pods) in faults and breccia zones trending N to NW with some trending NE.
   - Geology: Host rocks for the mineralization are rhyolites of the Tertiary Datil Formation. Gangue is calcite, quartz and rhyolite fragments. Faulting and tilting of older volcanic rocks are associated with intrusion of massive rhyolite centered near the northern part of the district. On the eastern side of the district, a N-S trending en echelon fault system is associated with the Rio Grande rifting. Altered rocks are silicified.

Production:	Production began in WWI and ended in 1957.

6. Cliff Deposit

Claims:	Cliff Nos. 1 to 3
Location:	33°57´2"N, 106°58´07"W NW-1/4 Sec. 20, T4S, R1W New Mexico Meridian
Commodity:	Mn
Ore Material:	Mn-oxides
Description of Deposit:	Small, north-striking ore body in a shear zone.
Geology:	The deposit is a fault-fracture structurally controlled ore body in Tertiary rhyolite of the Datil Formation. Mineralization occurred in the Tertiary. Calcite is a gangue deposit.
Production:	One carload of sorted ore was produced in WWI.

8. Socorro Peak District

Location:	34°4´N, 106°56´50"W
Commodities:	Ag, Mn, Ba Major product: Ag Minor products: Mn, Ba
Ore Materials:	Silver in quartz gangue, silver halides, galena Mn-oxides, vanadinite.
Description of Deposit:	Scattered veins and shear deposits trending N40°W.
Geology:	Mineralization is in Tertiary andesite tuff associated with Tertiary andesites, latite, rhyolite and monzonite. Mineralization is terminated by a clayey tuff and is post-Tertiary. Quartz and barite are present. Also nearby are the Pleistocene Palomas Formation (gravel) and Precambrian argillite. Alteration of ore-bearing rocks included silicification and kaolinitization. Termination at contact may be due to faulting between andesite tuff and clayey tuff.
Production:	Yes.

10. Merritt Mine (prior to 1870)
Claim patented in 1906 (Dewey Lode); Silver Bar Mine and the Boarding House Tunnel are also on the Dewey Lode

Location:	34°3´49"N, 106°56´30"W NE-1/4 of NE-1/4 of SE-1/4, Sec. 9, T3S, R1W New Mexico Meridian
Commodities:	Ag, Au, Pb, Zn, Cu, Ba, Mn, F, V, Mo, As Major products: Ag, Au Minor products: Pb, Zn, Cu Potential products: Ba, Mn, F Occurrences: V, Mo, As
Ore Materials:	Silver halides, argentite, native gold; galena wulfenite, descoloistite, mimetite, malachite, barite, Mn-oxides, fluorite, vanadanite.
Description of Deposit:	Ore body is a small, N-trending deposit dipping 35° to 65°W. The lode is composed of pods and shoots.

Geology: Mineralization is in faults and fractures in Tertiary trachyte and andesite. Gangue is quartz, barite, fluorite, Mn-oxides.
Production: Small.

12. Lucky Don and Little Davie Mines
Location: 34°5´54"N, 106°41´54"W
NE-1/4, Sec. 35, T2S, R2E, New Mexico Meridian
Commodities: U, V
Ore Materials: Tyuyamunite, carnotite.
Description of Deposit: The tabular-shaped Lucky Don deposit occurs along a NE striking fault zone as intergranular fillings and disseminations along fractures and bedding surfaces. The deposit is approximately 50 feet wide, 35 feet thick, and ranges from 300 to 400 feet in length. The Little Davie is similar, but smaller.
Geology: The deposit is located along a NE-trending fault between the Permian Yeso Formation and the Permian San Andres limestone. Mineralization of the structurally controlled deposit is late Tertiary or younger.
Production; Small.

13. Aqua Torres Mine
Location: 34°14´51"N, 106°40´40"W
SE-1/4 of T1S, R2E, New Mexico Meridian
Commodities: U, V
Description of Deposit: Shear zone; small deposit, north strike.
Geology: Deposits form a thin coating on fracture faces along a silicified breccia zone. Host rock is Pennsylvanian Madera limestone. Mineralization is along the north-trending fault zone between the Madera limestone and the Permian Abo sandstone, and is fault-fracture structurally controlled. Age of mineralization is late Tertiary or younger. Alteration--silicified limestone. Gangue is Fe-oxides, clay, silicified limestone.
Production: Small production from four open cuts.

15. Dewey Mine
Synonym Name: Jenkins Prospect
Location: 34°16´2"N, 106°49´36"W
SW-1/4, Sec. 35, T1N, R1E and NW-1/4 Sec. 2, T1S, R1E, New Mexico Meridian
Commodities: Ba, F, Pb
Major product: Pb
Minor products: Ba, F
Ore Materials: Barite, fluorite, galena.
Description of Deposit: The deposit is a vein with maximum length of 3,000 feet and maximum width of 5 feet.
Geology: The structurally controlled deposit was emplaced during the Tertiary along faults and fractures in Precambrian granites. Quartz is present as a gangue mineral.

Production: About 50 tons of lead ore was shipped in 1902.

17. Elaine Group

Claims: Elaine Nos. 1 to 7

Location: 34°8'38"N, 106°46'57"W
SE-1/4 Sec. 12, NE-1/4 Sec. 13 of T2S, R1E, and SW-1/4 Sec. 7, NW-1/4 Sec. 18, T2S, R2E New Mexico Meridian

Commodities: Ba, F, Pb
Past producer: Ba
Occurrences: F, Pb

Ore Materials: Barite, fluorite, galena.

Description of Deposit: The small, irregularly shaped vein with a maximum thickness of 2.5 feet strikes N5°E and dips 27° to the NW.

Geology: Mineralization occurs in fracture zones along bedding planes and rests on the west side of an anticline. Mineralization is in Paleozoic limestone and occurred in the Tertiary. Quartz and limestone inclusions are present as gangue.

Production: Small production is reported.

18. Martinez Prospect

Synonym Name: Arroyo de la Parida Area

Location: 34°3'52"N, 106°49'8"W
E-1/2 Sec. 10, T3S, R1E, New Mexico Meridian

Commodity: F

Ore Materials: Fluorite.

Description of Deposit: A 200 feet long by 2 feet wide pinch and swell vein along a northeast-trending vertical fault.

Geology: Tertiary mineralization along faults and fractures in Precambrian granite.

Production: About 50 tons of fluorite may have been shipped.

20. Torrence Mine

Synonym Names: New Find, Sixteen to One, Torrance Mine

Location: 34°3'50"N, 106°56'34"W
NW-1/4 of NE-1/4 of SE-1/4 Sec. 9, T3S, R1W, New Mexico Meridian

Commodities: Ag, Au, Pb, Zn, Cu, Ba, Mn, F, V, Mo, As
Major products: Ag, Au
Minor products: Pb, Zn, Cu
Potential products: Ba, Mn, F
Occurrences: V, Mo, As

Ore Materials: Silver halides, argentite, native gold, galena, wulfenite, descloisite, memetite, malachite, barite, Mn-oxides, fluorite, vanadinite.

Description of Deposit: A lode of small pods and shoots trending north and dipping 35° to 65°W.

Geology: Mineralization occurred in the Tertiary along faults and fractures in Tertiary rhyolites and trachytes. Gangue minerals are quartz, barite, fluorite, Mn-oxides.

Production: Small.

21. Grefco Perlite Mine

Location:	34°2'30"N, 106°55'45"W NE-1/4 Sec. 21, T3S, R1W, New Mexico Meridian
Commodity:	Perlite
Description of Deposit:	Small volcanic dome on Socorro Peak (late Tertiary or early Quaternary).
Geology:	Perlite is flow-banded, pumiceous, pale to buff-gray rhyolitic glass from dome. Dome is 450 feet high and 2,000 by 2,600 feet.
Production:	Open-pit mined from 1949-1961. Is one of principal domestic sources of perlite in U.S. Large reserves still present and mine has been reopened.

22. Unnamed Socorro Peak Kaolin Deposit

Location:	34°4'46"N, 106°56'44"W SE-1/4 Sec. 4, T3S, R1W, New Mexico Meridian
Commodity:	Kaolin clay
Ore Materials:	Kaolin.
Geology:	Kaolin was formed from the alteration of Tertiary rhyolites of the Datil Formation.
Production:	Some production for low-heat-duty firebrick.

23. Marie deposit

Location:	34°14'0"N, 106°36'2"W
Commodity:	U
Description of Deposit:	Small deposit in arkosic limestone immediately west of a fault. Fracture filling in limestone breccia.
Geology:	A steeply dipping, north-trending normal fault separates the Madera Formation and Abo Formation, with mineralization in an arkosic limestone member of the Madera Formation. Late Tertiary mineralizationa.
Production:	Small production from an open pit (1956).

27. Carthage Coal Field

Location:	33°51'57"N, 106°43'55"W Sec. 13, 14, 15, 16, 17, 20, 21, 22, 23 T5S, R2E New Mexico Meridian
Commodity:	Coal
Ore Materials:	Bituminous coal.
Description of Deposit:	Two coal seams are 4 to 7 feet thick each. The field is ten square miles in area.
Geology:	Coal seams occur in the terrestrial part of the Cretaceious Mesaverde Formation.
Production:	Yes; total unknown.

Known Prospects and Mineralized Areas with No Production Recorded

3. Carretas Canyon Group

Claims:	Optimo Nos. 1 to 12, Alto Nos. 1 to 5, Ultimo Nos. 1 to 9
Location:	33°59´1"N, 106°59´34"W W-1/2 Sec. 6, W-1/2 Sec. 7 and NW-1/4 Sec. 18, T4S, R1W and E-1/2 Sec. 1 and E-1/2 Sec. 12, T4S, R2W New Mexico Meridian
Commodities:	Mn, Pb, W
Ore Materials:	Psilomelane, pyrolusite, coronadite, W-bearing coronadite.
Description of Deposit:	Lode deposit of maximum 5 feet thickness striking N35°W, dipping 80°SW.
Geology:	The vein deposit is in a shear zone in Tertiary rhyolite of the Datil Formation; mineralization is also Tertiary. Calcite and brecciated rhyolite make up the gangue material.
Production:	Undetermined.

7. Unnamed Manganese Occurrences

Location:	7/1: 34°0´24"N, 106°58´30"W (SW-1/4 Sec. 32, T3S, R1W); 7/2: 33°54´13"N, 106°58´7"W (SW-1/4 Sec. 5, T5S, R1W); 7/3: 34°00´12"N, 107°00´17"W (S-1/2 Sec. 36, T3S, R2W) New Mexico Meridian
Description of Deposits:	Small.
Production:	Unknown.

11. Carter-Tolliver-Cook

Location:	W-1/2 Sec. 6, T2S, R1W E-1/2 Sec. 5, T2S, R1W New Mexico Meridian
Commodities:	U, possibly Pb and Cu
Ore Materials:	Carnotite, uranophane associated with galena, pyrite, chalcopyrite.
Geology:	Minerals occur in mafic dikes that crosscut diorite intrusive bodies. Igneous rocks probably intrude Santa Fe Group. Grab(?) sample yielded 0.25% U_3O_8.
Production:	Unknown.

14. Box Canyon Prospect

Claims:	Box Canyon Nos. 1 and 2
Location:	34°09´31"N, 106°59´19"W, SW-1/4 Sec. 6, NW-1/4 Sec. 7, T2S, R1W, New Mexico Meridian
Commodities:	Ba, F,
Ore Materials:	Barite, fluorite.
Description of Deposit:	Lode (vein) deposit. Maximum thickness is 2.5 feet. Ore body strikes N35°W, dipping 75°NE.
Geology:	Mineralization is in Pennsylvanian Madera limestone along contact with Precambrian granite. Age of mineralization is Tertiary. Gangue materials are quartz and wall rock fragments.
Production:	None

16. Gonzales Prospect

Claims: Gonzales Nos. 1 and 2

Location: 34°04´48"N, 106°48´13"W
NE-1/4 Sec. 2, T3S, R1E,

Commodities: F, Ba, Pb, Zn
Major products: F, Ba
Occurrences: Pb, Zn

Ore Materials: Barite, fluorite, galena, sphalerite

Description of Deposit: Vein with pinch and swell form, thickness ranges from 3 feet to 22 feet, maximum length of 850 feet. Ore body strikes N6° to 30°W and dips 70° to 80°SW.

Geology: Mineralization is structurally controlled and is found along faults and fractures. Most rock is Pennsylvanian Madera limestone at its contact with Precambrian granite. Mineralization occurred in the Tertiary and quartz is present as gangue.

Production: None.

19. La Bonita Prospect

Synonym Name: Tienda Claims

Location: 34°4´7"N, 106°47´57"W
NE-1/4 Sec. 11, and NW-1/4 Sec. 12 of T3S, R1E, New Mexico Meridian

Commodities: F, Ba

Ore Materials: Fluorite, barite.

Description of Deposit: Deposit is composed of small, lense-shaped lodes along two N25°W striking faults that dip 60°-65°SW. The three largest lenses range from 85 feet to 150 feet in length and 1.7 feet to 2.5 feet in thickness.

Geology: Mineralization occurred in the Tertiary and is structurally controlled. Mineralization is in the Pennsylvanian Madera limestone, with quartz present as gangue.

Production: None.

24. Bursum Deposit

Location: 33°58´52"N, 106°58´43"W
SW-1/4, NE-1/4 Sec. 7, T4S, R1W,
New Mexico Meridian

Commodity: Mn

Ore Materials: Psilomelane.

Description of Deposit: Mineralization along faults and in shear zones.

Geology: Mineralization occurred along faults and shear zones in rhyolites of the Tertiary Datil Formation.

Production: Unknown.

25. Barrett Mine

Location: 33°59´7"N, 106°59´50"W
SE-1/4 Sec. 1, and NE-1/4 Sec. 12, T4S, R2W, New Mexico Meridian

Commodity: Mn

Description of Deposit: Veins along faults and in shear zones.

Geology: Mineralization is along faults and shear zones in rhyolites of the Tertiary Datil Formation.

Production: Unknown.

26. Unnamed Uranium Occurrences

Locations:

26/1. 34°9´24"N, 107°0´53"W, SE-1/2 Sec. 2, T2S, R2W
26/2. 34°15´9" N, 107°0´45"W, NE-1/4 Sec. 2, T1S, R2W
26/3. 34°16´5" N, 107°0´37"W, SE-1/4 Sec. 36, T1N, R2W
26/4. 34°5´55" N, 107°0´0"W, N-1/2 Sec. 36, T2S, R2W
26/5. 33°57´21" N, 106°58´28"W, NE-1/4 Sec. 19, T4S, R1W
26/6. 34°1´20" N, 106°57´34"W, W-1/4 Sec. 28, T3S, R1W
26/7. 34°1´18" N, 106°56´28"W, SE-1/4 Sec. 28, T3S, R1W
26/8. 34°13´21" N, 106°58´55"W, SE-1/4 Sec. 18, T1S, R1W
26/9. 34°11´27" N, 106°58´45"W, SE-1/4 Sec. 30, T1S, R1W
26/10. 34°12´24" N, 106°58´6"W, center Sec. 20, T1S, R1W
26/11. 34°9´39" N, 106°57´26"W, SW-1/4 Sec. 4, T2S, R1W
26/12. 34°17´12" N, 106°56´59"W, E-1/2 Sec. 21, T1N, R1W
26/13. 34°16´49" N, 106°56´3"W, SE-1/4 Sec. 22, T1N, R1W
26/14. 34°6´4" N, 106°48´27"W, SE-1/4 Sec. 26, T2S, R1E
26/15. 34°3´49" N, 106°48´21"W, center Sec. 11, T3S, R1E
26/16. 34°2´46" N, 106°48´5"W, SE-1/4 Sec. 14, T3S, R1E
26/17. 34°7´50" N, 106°48´20"W, SE-1/4 Sec. 14, T2S, R1E
26/18. 33°52´22" N, 106°45´15"W, SE-1/4 Sec. 17, T5S, R2E
26/19. 34°15´45" N, 106°46´3"W, SE-1/4 Sec. 31, T1N, R2E
26/20. 34°13´12" N, 106°43´53"W, SW-1/4 Sec. 15, T1S, R2E
26/21. 34°16´52" N, 106°43´3"W, SE-1/4 Sec. 27, T1N, R2E
26/22. 33°57´50" N, 106°40´12"W, center Sec. 18, T4S, R3E
26/23. 33°58´55" N, 106°39´21"W, NW-1/4 Sec. 8, T4S, R3E

Commodity: U

Geology: Unknown. Locations are from USGS Map I-1327, no other information available.

Production: Unknown.

28. Jornada del Muerto Field

Location: 33°57´2"N, 106°37´30"W
Secs. 16, 17, 20, 21, 28, 29, 32 and 33, T3S, R3E and Sec. 36, T4S, R2E and Secs. 3, 4, 9, 10, 11, 13, 14, 15, 16, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, T4S, R3E and Secs. 19, 30, 31, T4S, R4E and Secs. 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, T5S, R3E New Mexico Meridian

Commodity: Coal

Ore Materials: Bituminous coal.

Description of Deposit: Coal bed is 3 feet thick and very extensive.

Geology: The coal bed occurs in the terrestrial part of the Cretaceous Mesaverde Formation.

Production: None.

Thermal Springs of the Socorro GRA

30. Socorro Peak East No. 1: SW-1/4, SW-1/4, SE-1/4 Sec. 4, T3S, R1W. Temperature gradient = 159 + 2°C/km.

31. Socorro Peak East No. 2: SW-1/4, NE-1/4 Sec. 9, T3S, R1W. Temperature gradient = 10-25m, 245 + 24°C/km; 24-40m, 159 + 11°C/km.

32. Blue Canyon East No. 1: SE-1/4, NW-1/4 Sec. 15, T3N, R1W. Temperature gradient = 10-20m, 119 + 20°C/km; 35-70m, 35.5 + 0.2°C/km.

33. Blue Canyon East No. 2: NW corner SW-1/4 and SW corner NW-1/4 Sec. 15, T3S, R1W. Temperature gradient = 10-20m, 98.2 + 12.2°C/km; 20-100m, 19.3 to 39.2°C/km.

34. Socorro Canyon East: center SW-1/4, SW-1/4 Sec. 27, T3S, R1W. Temperature gradient = 10-20m, 83.7 + 14.3°C/km; 25-110m, 45.6 to 50.1°C/km.

35. Nogal Arroyo No. 1: SW-1/4, NE-1/4, SW-1/4 Sec. 26, T2S, R1W. Temperature gradient = 10-20m, 96.2 + 6.7°C/km.

36. Nogal Arroyo No. 2: SW corner Sec. 26 and NW corner Sec. 35, T2S, R1W. Temperature gradient = 10-20m, 93.9 + 13.4°C/km.

37. New Mexico Tech Golf Course: center NW-1/4, NE-1/4 Sec. 11, T3S, R1W. Temperature gradient = 10-20m, 96.9 + 1.9°C/km; 20-25m, 44.4°C/km.

38. Nogal Canyon: NW-1/4, SE-1/4, NE-1/4 Sec. 1, T3S, R2W. Temperature gradient = 10-20m, 97.9 + 28.6°C/km; 15-35m, 28 - 47.8°C/km.

39. Thermal well or spring: SW-1/4, Sec. 10, T2S, R1W. Water temperature at surface = 20°C.

40. Thermal well or spring: SW-1/4, Sec. 31, T1N, R1E. Water temperature at surface = 21°C.

41. Thermal well or spring: W-1/2, Sec. 19, T3S, R2E. Water temperature at surface = 26°C.

42. Three thermal springs: SW-1/4, Sec. 22, T3S, R1W. Water temperature at surface + 33°C. Calculations using the method of Fournier and Truesdell, 1973, yielded a source temperature of 62°C, based on chemical data of Summers, 1965.

Thermal springs or well number 1 through 9 are located in the Socorro Peak Known Geothermal Resource Area (KGRA).

29. Unnamed Coal Field

Location:	T1N, R2E
Commodity:	Coal
Ore Materials:	Bituminous or sub-bituminous coal.
Geology:	Unknown.
Production:	Unknown.
Note:	Location is approximate.

Mining Claims and Leases

Mining claims recorded by the BLM and reported as currently (April, 1982) active in the three WSAs include only 24 unpatented claims. All these claims are located within the Township 3S and Range 2E. These claims and claim blocks are listed in Table 1. The Ranger Industries claims are believed to be for copper-silver and/or for uranium. They cover mostly outcrops with Abo Formation. At the present time, there is no mining activity in the area and no visible signs of the assessment work were noted during field verification.

Oil and gas leases have been issued in all WSAs (P.F. King, 1982, pers. comm.).

Mineral Deposit Types

Geological environments of the Socorro GRA considered potentially favorable for the occurrence of mineral or energy resources include:

- Precambrian metamorphic rocks
- Paleozoic sedimentary rocks,
- Permian redbeds,
- Cretaceous coal measures,
- fossil hydrothermal systems associated with Oligocene to Quaternary volcanism,
- late Tertiary valley-fill sediments,
- Quaternary alluvium, and
- active geothermal systems.

Precambrian Metamorphic Rocks

Felsic metavolcanic rocks associated with massive sulfide deposits in Arizona (Anderson and Guilbert, 1979) form a 1.6-1.9 b.y. old belt which

TABLE 1
CLAIM DENSITY RECORDS IN THE WILDERNESS STUDY AREAS, SOCORRO GRA
ACCORDING TO BLM (APRIL 1982), NEW MEXICO OFFICE, SANTA FE

Township	Range	Section	Claims for Each Section	Claimants	Latest Assmt. Date
3S	2E	4	NW 1	Ranger Industries	1980
			W2 1	"	"
			SW 1	"	"
		5	NE 2	"	"
			E2 2	"	"
			SE 2	"	"
		6	E2 2	"	"
			SE 1	"	"
		7	NE 1	"	"
			SE 1	"	"
		20	SE 1	Griego, Tom	none L/D 5-5-81
		21	NE 4	Armijo, Sam	1981
			E2 1	Armijo, Lydio A.	"
			SE 2	Armijo, Polo Jr.	"
		22	SW 2		"

extends into northern New Mexico. The Proterozoic of central New Mexico also contains felsic metavolcanics but the rocks are distinctly younger than the Arizona metavolcanics (Condie and Budding, 1979) and there are no known massive sulfides deposits within the Proterozoic rocks of New Mexico.

Paleozoic Sedimentary Rocks

Oil and gas have long been produced from the Paleozoic rocks of southeastern New Mexico, with most of the oil production coming from Permian rocks. In the GRA, potential source rocks are black marine shales of the Sandia and Mancos Formations, and the potential reservoir rocks are sandstone in the upper Madera, Abo and Yeso Formations and the Glorieta sandstone. Oil and gas are unlikely to have been trapped in significant quantities in the western two-thirds of the GRA because of faulting associated with Oligocene volcanism, with Miocene to Quaternary volcanism and rifting along the Rio Grande.

Two dry wells have been drilled within the GRA (U.S. Geological Survey, 1981; Arnold and Hill, 1981).

Permian Redbeds

Redbed copper deposits, often containing silver, are found in Permian and Triassic rocks and are widely distributed throughout central and north-central New Mexico (LaPoint, 1974a). Several occurrences are known in the eastern part of the Socorro GRA (P.F. King, 1982, pers. comm.), and one occurrence was discovered in the Veranito WSA during this study. Outside the GRA, redbed-type copper mineralization is found in the Estey district where uneconomic concentrations of malachite, azurite and lesser hematite, pyrite, bornite, chalcocite, covellite, chalcopyrite and melaconite are found mainly in arkosic channel deposits within the Bursum and Abo Formations. The copper-rich zones are 1-3 feet thick and copper minerals cover fractures, fill voids, coat detrital grains and are most abundant replacing and surrounding plant debris. In the Scholle (see fig. 1) district chalcocite replaces wood in reddish brown sandstone and organic-rich shales below fluvial channels in the Abo Formation. In the Nacimiento region of north-central New Mexico, chalcocite, covellite, bornite, chalcopyrite and pyrite are associated with carbonaceous material such as fossil log jams in arkosic sandstone paleochannels. The deposits occur in the Abo Formations and the Agua Zarca member of the Chinle Formation.

The redbed copper deposits of New Mexico were first studied by Lindgren et al., (1910) who favored an origin involving hydrothermal fluids rising along faults and spreading out along permeable aquifers. Most recent workers, such as LaPoint (1974a, 1974b) and Woodward et al., (1974), favor deposition from circulating groundwater in response to a local lowering of Eh. The ultimate source of the copper is considered to be Precambrian copper deposits and/or copper-enriched lithologies.

The Yeso Formation also contains abundant gypsum-rich evaporites. Fifteen miles northeast of Socorro, Weber and Kottlowski (1959) report 100-150 feet of gypsum within the Canas member. Such evaporitic sequences suggest the possibility of "sabkha"-type copper deposits being present within this formation (see Renfro, 1974).

Cretaceous Coal Measures

The three coal deposits within the Socorro GRA occur in the terrestrial part of the Mesaverde Group. The most important coal field is the Carthage field where a coal seam 4-7 feet thick, extends over ten square miles. Coal does not underlie any of the WSAs.

Oligocene to Quaternary Hydrothermal Deposits

The hydrothermal deposits have been described in the previous section. They can be divided into the following types according to the principal commodities present: manganese deposits, silver $\pm$ gold associated with base metals, barite with fluorite generally associated with lead, and uranium and vanadium.

Manganese deposits of the Luis Lopez district all occur along breccia zones in rhyolites of the Datil Formation and have been described by Miesch (1956), Jicha (1956), and Hewett and Fleischer (1960). The principal manganese minerals are psilomelane, pyrolusite, wad, coronadite ($Pb(Mn,Cu,Zn)_8O_{16}$), cryptomelane ($K(Mn,Zn)_8O_{16}$) and hollandite (Ba,Mn_8O_{16}). Gangue minerals are calcite, anhydrite, quartz, gypsum, barite and minor fluorite. Ore produced from the Luis Lopez district during the early 1950s typically contained Mn (50%); Cu (0.02-0.08%); Pb (0.1-4.3%); Zn (0.1-0.55%) Ba (10-13%) and, locally, up to 0.24% U_3O_8. Jicha (1956) concluded that the ores are of hypogene, rather than supergene, origin because: presence of ore does not depend on topography, it often increases in thickness and grade with depth, blind ore bodies occur, it is structurally controlled, the ore contains anhydrite and unusual concentrations of base metals and tungsten, and there is a district-wide zonation of Pb with the content increasing in a northeasterly direction. On the basis of regional studies of manganese deposits, Hewett and Fleischer (1960) concluded that the deposits were formed from hydrothermal fluids associated with late stages of volcanic activity. Similar manganese deposits lie along a N-S zone extending from Durango, Mexico, to Socorro, New Mexico.

Hydrothermal silver deposits such as the Torrence mine, Merritt mine and the Socorro Peak district deposits are fault-controlled and are associated with felsic volcanic rocks of the Datil Formation. Important ore minerals are argentite, cerargyrite, native gold, galena, barite, fluorite, vanadinite, and manganese oxides. In addition, anomalous concentrations of copper, zinc and molybdenum are reported. They differ from the manganese deposits in that the principal commodities are silver and gold, but are similar in that they occur along faults in volcanics and carry significant manganese, barite, fluorite and base metals.

Deposits of barite with fluorite occur along faults within Precambrian rocks (Martinez prospect and the Dewey mine) or in limestones of the Madera Formation (Elaine, Box Canyon, Gonzales, La Bonita Prospects). The principal minerals are barite, fluorite, galena and local sphalerite. Similar mineralization is found in the Hansonburg mining district to the southeast of the GRA. Here barite, quartz, fluorite and galena, often occurring as perfect crystals, occur along faults in silicified Madera limestone (Kottlowski, 1953). In the Linchburg ore body of the Magdalena district, to the west of the GRA, the same minerals occur in a garnet-pyroxene-hematite skarn replacement deposit (Titley, 1961). The skarn is in the Kelly limestone and is associated with a major fault and latite porphyry dikes.

The barite-fluorite mineralization in the GRA is similar to the manganese and the silver deposits as all occur along faults, contain barite and fluorite and are enriched in lead, and are probably related to volcanism.

The uranium and vanadium deposits occur along faults cutting limestones of the San Andres Formation (Lucky Don and Little Davie mines) and the Madera Formation (Aqua Torres and Marie mines) (Hilpert, 1969). The deposits contain up to 14 ppm Ag, 13 ppm Mo, 890 ppm F, 2,100 ppm Zn and 3.3% S (Hilpert, 1969). A possible relationship to the barite-fluorite mineralization is suggested by the anomalous silver, zinc and fluorine contents of these deposits and by the fact that they also lie along faults in limestones.

It is possible that all of the above types of hydrothermal deposits are associated with Tertiary volcanic activity. Elston (1978) has suggested that some major hydrothermal deposits are associated, in both space and time, with Oligocene cauldrons. Kesler (1977) has suggested that manto fluorite deposits lie on a north- to northeast-trending belt from northern Coahuila, Mexico through central Mexico and are associated with alkaline volcanics and normal faulting. Damon et al., (1981) and Clark et al., (1982) also show a northeast- and north-trending belt of fluorite mineralization that goes through Socorro and the Hansonburg mining district, and a molybdenum belt which runs slightly to the east of the GRA and includes the Cave Creek, Nogal Peak, Questa, Urad, Henderson and Climax deposits. These belts are considered to be related to high K calc-alkaline to alkaline volcanism of Oligocene age represented by the Datil Formation in the GRA. They were erupted at a time when the Farallon plate was dipping at a shallow angle beneath North America.

None of the hydrothermal deposits are known to be present in any of the WSAs.

Late Tertiary Valley-Fill Sediments

Valley-fill sediments of the Popotosa and Santa Fe Formations underlie the Rio Grande valley and a large part of the Veranito WSA. These sediments probably represent a potentially favorable environment for stratabound uranium deposits. According to Hilpert (1969), the favorability for occurrence of uranium deposits in the Popotosa and Santa Fe Formations is poor at the surface and good at depth. According to Pierson et al., (1982) sediments of the Baca Formation are favorable for the occurrence of sandstone-type uranium deposits.

In order to form a uranium deposit by the agency of circulating groundwater it is necessary to have adequate source rocks, permeable sediments and a suitable reductant. Both formations contain clasts of rhyolitic Datil volcanics and coeval rhyolitic ash. Both are probably suitable sources of uranium, and Miesch (1956) reports that Datil rhyolites contain between 10-50 ppm eU. Both formations contain abundant sandstones and gravels (Denny, 1940) and are undoubtedly sufficiently permeable. It is not certain, however, whether adequate reductants are present within the formations to cause precipitation of uranium. Suitable reductants would be organic matter within the sediments or reducing geothermal fluids. The latter would appear as possible reductants in light of present-day and past geothermal activity in the Rio Grande rift and surrounding areas (Chapin et al., 1978).

Quaternary Alluvium

Quaternary alluvium represents a possible site where placer gold might be concentrated. In the Socorro GRA, there are no known placer gold occurrences.

Active Geothermal Systems

Evidence for the presence of some geothermal activity in central New Mexico is found in the form of widespread, though generally low temperature, hot springs. Factors that are favorable for the existence of substantial active geothermal systems include: the presence of a high temperature heat source, such as an underlying magma chamber; the presence of aquifers which allow large volumes of water to circulate through the hot rocks; and the presence of cap rocks which will prevent the escape of at least some of the geothermal energy to the surface.

In the western third of the Socorro GRA all of the above factors appear favorable. An adequate heat source appears to be present. This is indicated by the following:

1. In the area of the Socorro trough, the heat flow is greater than 2.5 hfu.
2. Thirteen warm springs are present in the area. The springs have surface temperatures of up to 33°C (see previous section).
3. Thermal gradients of up to 160°C/km have been measured within the Known Geothermal Resource Area (KGRA) (see previous section).
4. According to Sanford et al., (1979), several shallow (4-5 km) magma chambers are present below the Socorro Peak KGRA.

Premeable rocks are also present in the western part of the GRA. High permeability is present within the valley-fill sediments of the Socorro trough and high secondary permeability may be associated with the Socorro cauldron (Chapin et al., 1978) and with the faulting related to the formation of the Rio Grande rift. An impermeable cap in the form of a gypsum-bearing claystone is present in the Popotosa Formation (Chapin et al., 1978).

The Veranito WSA overlies the Rio Grande rift and its eastern margin and is close to one of the inferred shallow magma chambers. The Sierra las Canas WSA lies along the faulted margin of the Rio Grande rift, and is about six miles from one of the shallow magma chambers. A warm spring (26°C) is present near its western boundary. No evidence of geothermal activity is present near the Stallion WSA.

Mineral Economics

The following is a discussion of the economics of mineral and energy production in the Socorro GRA.

Manganese was produced from deposits within and adjoining the GRA only when artificial price supports were in effect during U.S. government stockpiling in the 1950s and earlier. It is not likely that these small deposits will again be economic without artificial supports.

Hydrothermal gold-silver-lead-zinc-copper deposits of the Socorro Peak area are small and never produced much ore. Stratabound copper deposits are reported to occur in Permian redbeds to the north and south of the GRA, and occurrences are reported within the GRA, but deposits are small.

There has been small production in the past from structurally controlled uranium and barite-fluorite vein deposits in Paleozoic sediments in the GRA. It is possible some stratabound uranium deposits may be present in rocks of the Santa Fe Formation, although no occurrences have been reported. It is unlikely that any of these deposit types could be economic at this time, but conditions may again become favorable for the exploration and production of uranium. The Veranito WSA is underlain by the Santa Fe Formation and may be a potential uranium producing area.

Three oil exploration wells have been drilled in the GRA, but all were dry. If any oil or gas was originally present in Paleozoic sediments of the GRA, it likely has disappeared as a result of faulting associated with Rio Grande rifting. Oil and gas possibilities are greater in the eastern part of the GRA, which is less faulted.

The Socorro Peak Known Geothermal Resource Area (KGRA) contains many thermal springs with surface temperatures up to 33°C, has heat flow greater than 2.5 hfu, and is underlain by several small magma bodies at 4-5 km depth and one large, sheet-like magma body at 18-19 km depth. Exploration is ongoing and power production is possible. Even if no power is produced from the KGRA, it must be considered as a source of heat for the nearby town of Socorro.

Impure gypsum-bearing sediments comprise 12% of the Yeso Formation (Weber and Kottlowski, 1959). Gypsum of higher purity and easy access is common in central New Mexico in playa lakes and in dunes, thus, the deposits within the Yeso are unlikely to be of economic value.

Coal is unlikely to become economic in the GRA. All strippable coal has been removed from the Carthage coal field. Both the Carthage field and the Jornada del Muerto field contain thin beds of coal that are folded and faulted, thus increasing the difficulty and cost of mining.

Basalt and rhyolite, sand and gravel, and limestone (especially in the San Andres Formation) are common in the GRA and are likely to be useful in the local building industry. The Socorro perlite deposit is an important domestic source of perlite and still contains large reserves (New Mexico Bureau of Mines and Mineral Resources, 1965). Bentonite, resulting from diagenesis of tuffaceous beds found in the Santa Fe Formation, could be suitable for use in drilling mud (New Mexico Bureau of Mines and Mineral Resources, 1965).

LAND CLASSIFICATION FOR GEM RESOURCES POTENTIAL

The areas covered by the GRA and the WSAs are classified with respect to their resources potential and level of confidence according to the schemes provided by the Bureau of Land Management (attachment 9, dated 3/24/82). The data on which this classification is based is presented in a preceding part of this report. The potential resources are divided into locateable, leaseable and saleable categories.

Metallic Minerals

Potentially favorable environments for the occurrence of metallic minerals within the Socorro GRA include: stratabound copper $\pm$ silver in Permian redbeds, structurally controlled hydrothermal deposits of manganese with minor Cu, Pb, Zn, W, Ba, U), silver ± gold (with minor Cu, Pb, Zn, Mo, Mn, V, Ba, F), and lead ± zinc (with barite and fluorite), probably associated with Oligocene volcanic cauldrons; and gold in placers.

1. Stratabound copper ± silver deposits. This type of deposit is known to occur within the GRA (P.F. King, 1982, pers. comm.) and occurrences and mines are widespread in Permian redbeds of central and north-central New Mexico (La Point, 1974a). Geologically, the Permian redbeds of the Socorro GRA are moderately favorable for the occurrence of this type of deposit. The GRA is assigned a moderate favorability (3) at a confidence level of B.

   In the Veranito WSA the Permian redbeds are deeply buried below Tertiary volcanic and sedimentary rocks. Therefore, the WSA is not favorable (1) for the occurrence of stratabound copper deposits at a confidence level of B.

   The Stallion and Sierra las Canas WSAs contain extensive outcrops of Permian redbeds, therefore, these WSAs are assigned a moderate favorability (3) at a confidence level of B.

2. Hydrothermal manganese deposits. There was production of several thousand tons of manganese ore, with various byproducts, from the Luis Lopez district during the 1950s at a time of government stockpiling. It is not likely that the mines will be reopened under present circumstances but could become producers if overseas supplies of manganese were cut off. The GRA lies within a zone extending from Durango to Socorro in which similar volcanic-hosted deposits occur (Hewett and Fleischer, 1960).

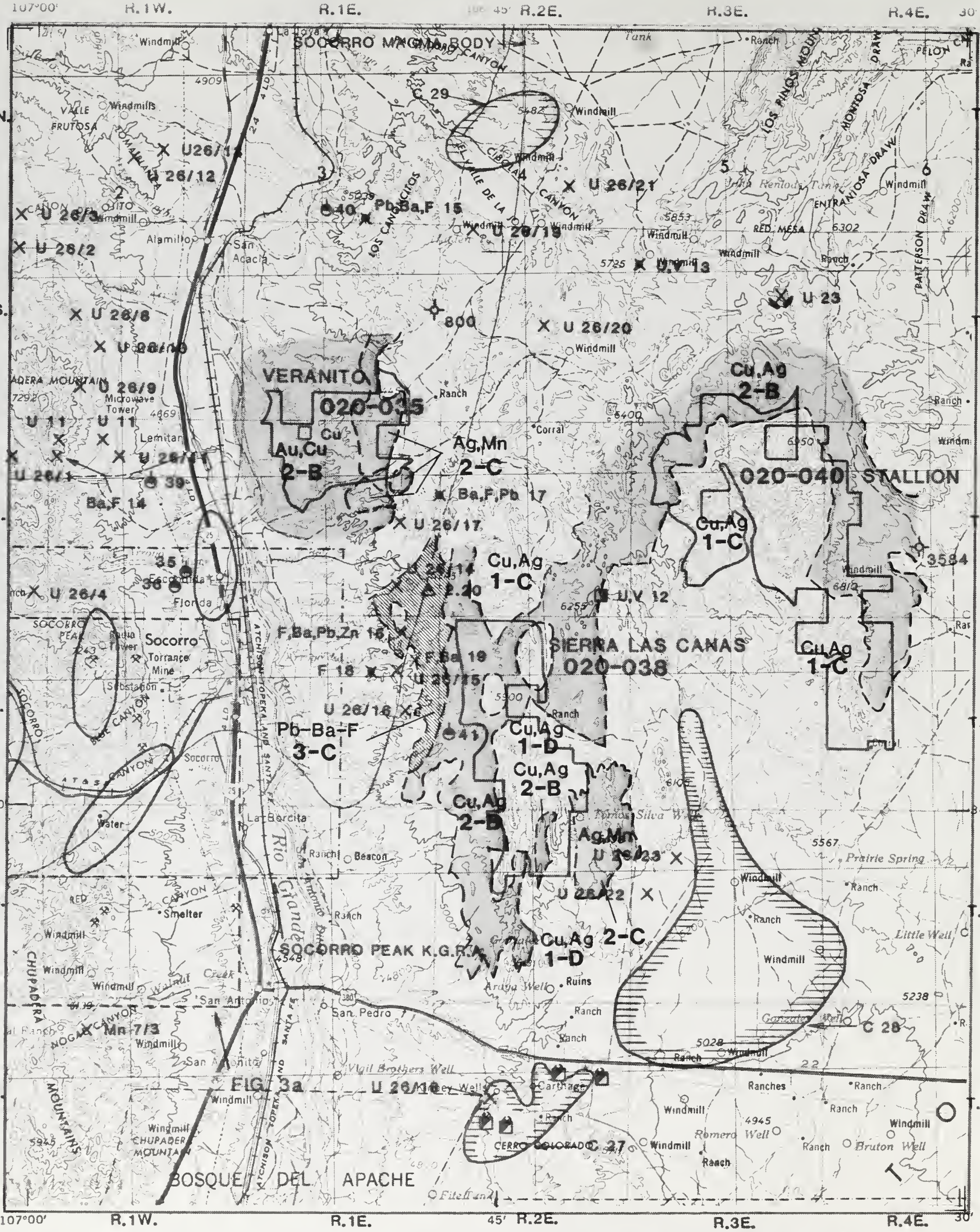


FIG. 5 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR HYDROTHERMAL SILVER (Ag), LEAD-BARITE-FLUORITE (Pb-Ba-F), STRATABOUND (Cu, Ag), HYDROTHERMAL MANGANESE (Mn), AND PLACER GOLD (Au) RESOURCES OF THE SOCORRO AREA, NEW MEXICO.

The volcanic rocks in the western part of the GRA are favorable for the occurrence of hydrothermal manganese deposits. This area contains two cauldrons with which the hydrothermal deposits may be associated. The GRA is assigned a high favorability (4) at a confidence level of D.

The Veranito WSA contains Datil volcanics but contains no known manganese occurrences. The Socorro area has been prospected intensely for manganese in the 1940s and 1950s, therefore, the WSA is assigned a low favorability (2) at a confidence level of C.

The Sierra las Canas and Stallion WSAs contain no volcanic rocks and are considered not favorable (1) at a confidence level of D.

3. Hydrothermal silver deposits. There has been small production of silver and gold and various byproducts from the Socorro Peak district and the Merritt mine. The mineralization is associated with Oligocene cauldrons, several of which are present nearby. The GRA lies close to a mid-Tertiary molybdenum porphyry belt extending from Texas to Colorado (Damon et al., 1981; Clark et al., 1982), but there are no known large disseminated deposits in this area. Such deposits could underlie some of the cauldrons in the Socorro area. The GRA is assigned a moderate favorability (3) at a confidence level of B.

   The Veranito WSA contains Datil volcanics and is approximately six miles from the edge of the Socorro cauldron. No hydrothermal precious or base metal occurrences are present on or near the WSA and it is assigned a low favorability (2) at confidence level of B. The Stallion and Sierra las Canas WSAs contain no volcanics and are not favorable (1) for the occurrence of this type of deposit at a confidence level of D.

4. Hydrothermal lead ± zinc deposits. Production of 50 tons of lead from the Dewey Mine and smaller production from several other mines and prospects are reported from the GRA. These deposits occur along faults in Precambrian rocks and in the Paleozoic Madera limestone and are invariably associated with barite and fluorite. The GRA lies within a zone extending from Coahuila to New Mexico (Kesler, 1977) in which similar deposits occur and are associated with alkaline volcanism. The GRA is assigned a moderate favorability (3) at a confidence level of C.

   The Veranito WSA does not contain basement rocks or Paleozoic limestones exposed at the surface and it is not favorable (1) for the occurrence of this type of deposit at a confidence level of D. The Sierra las Canas WSA contains Paleozoic limestones, including the Madera limestone, and is cut by numerous faults. Several occurrences containing barite and fluorite lie within a mile of the WSA border and it is assigned a moderate favorability (3) at a confidence level of C. The Stallion WSA contains Paleozoic limestones but it is not intensely faulted and no occurrences are known within or near its borders. It is assigned a low favorability (2) at a confidence level of C.

5. Placer gold. There are no known gold placers in the GRA. However, hydrothermal gold is reported in the Chupadera

range in the western part of the GRA and alluvial gold could have accumulated in the Tertiary basin-fill sediments and in Quaternary alluvium of the Socorro trough. The GRA is assigned a low favorability (2) at a confidence level of B.

The Veranito WSA contains Tertiary valley-fill sediments and Quaternary alluvium. It is assigned a low favorability (2) at a confidence level of B. The other two WSAs do not contain any Tertiary valley-fill sediments or alluvium and are considered not favorable (1) at a confidence level of D.

Uranium and Thorium

Potentially favorable environments for the occurrence of uranium minerals within the Socorro GRA include: structurally controlled uranium deposits in Precambrian granite and Paleozoic limestone that are possibly related to Oligocene volcanism, and stratabound uranium in late Tertiary valley-fill sediments. There are no known favorable environments for thorium.

1. Six granitic outcrops of probable late Precambrian age are exposed in an area of 5,000 acres largely covered by Paleozoic and Tertiary sedimentary rocks (Wilpolt, 1951). All the granite exposures exhibit abnormal radioactivity, 3 to 24 times background. All exposures are deeply weathered.

   Geochemical sampling shows anomalous values in a mineral suite that correlates with the Rossing suite and with that of other bodies of similar geology (Fieldman, 1977).

   Geochemical uranium values in 46 of 68 samples are 5 to 200 times the accepted value for normal granite. Yellow uranium minerals and bright green-yellow fluorescence indicate that a major portion of the uranium is present in the hexavalent or soluble state. A grab sample from a shallow cut, probably excavated in the 1950s, assayed 4350 ppm. Radioactivity in the overlying and surrounding rock is 4 to 6 times background.

Primary and secondary mineralization, accompanied by hematite, limonite, fluorite and brown chert, is controlled by closely spaced fractures. Prominent northwest trending faults are late and barren.

2. Uranium deposits in Paleozoic limestone. Four small deposits of uranium and vanadium occur along faults in the San Andres and Madera Formations. Only minor production is reported from them. The mineralization may be related to late Tertiary volcanism. The area was probably intensely prospected for uranium in the 1950s and recently. The GRA is assigned a low favorability (2) at a confidence level of C.

   The Veranito WSA does not contain outcrops of Paleozoic limestone and it is considered not favorable (1) at a confidence level of D. The Sierra las Canas and Stallion WSAs contain outcrops of Paleozoic limestones but do not contain any uranium occurrences. They are both assigned a low favorability (2) at a confidence level of C.

3. Stratabound uranium in late Tertiary valley-fill sediments. No uranium occurrences of this type are known to occur in the GRA. However, the Popotosa and Santa Fe Formations could be hosts for roll-type stratabound uranium deposits because both formations contain uranium-rich volcanic source rocks, contain permeable horizons and may contain reductants such as organic matter or reducing geothermal fluids. Therefore, the GRA is assigned a moderate favorability (3) at a confidence level of B.

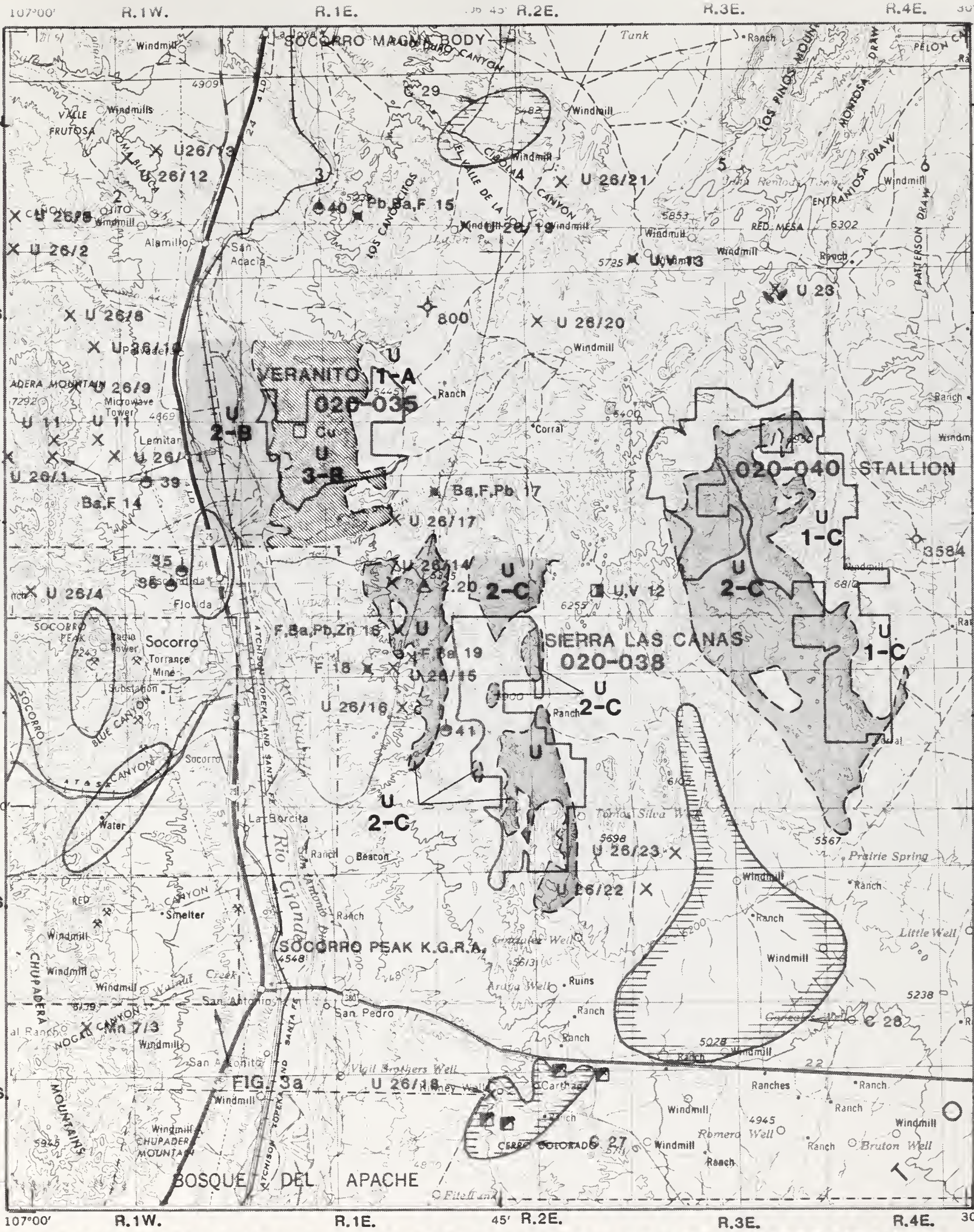


FIG.6 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR URANIUM IN LIMESTONE RESOURCES OF THE SOCORRO AREA, NEW MEXICO.

The Veranito WSA is partly underlain by the Santa Fe Formation and possibly underlain by the Popotosa Formation. It is assigned a moderate favorability (3) at a confidence level of B. The Stallion and Sierra las Canas WSAs do not contain any Tertiary valley-fill sediment and are not considered favorable (1) at a confidence level of D.

Non-Metallic Minerals

Potentially favorable environments for the occurrence of non-metallic minerals in the Socorro GRA include: hydrothermal, structurally controlled barite-fluorite (with lead $\pm$ zinc) deposits, possibly related to alkaline volcanism, and hydrothermal kaolin deposits in Datil Formation rhyolites.

1. Hydrothermal barite-fluorite deposits. About 50 tons of fluorite were produced from the Martinez prospect and lesser amounts from several other locations. These deposits occur along faults in Precambrian rocks and in the Madera limestone and are generally associated with galena and, locally, sphalerite. The GRA lies within a zone extending from Coahuila to New Mexico (Kesler, 1977) in which similar deposits occur and are thought to be associated with alkaline Tertiary volcanism. The Hansonburg mining district, where fluorite, barite and lead were mined, lies a few miles to the southeast of the GRA. The GRA is assigned a moderate favorability (3) at a confidence level of C.

   The Veranito WSA does not contain basement rock of Paleozoic limestones exposed at the surface and is classified as not favorable (1) at a confidence level of D. The Sierra las Canas WSA contains Paleozoic limestones, including the Madera, and is cut by numerous faults. Several occurrences containing barite and fluorite lie within a mile of the WSA border and the WSA is assigned a moderate favorability (3) at a confidence level of C. The Stallion WSA contains barite and fluorite within or near its borders. It is assigned a low favorability (2) and confidence level of C.

2. Hydrothermal kaolin deposits. One kaolin deposit occurs near Socorro Peak from which there has been some production. It formed as a result of hydrothermal alteration of rhyolite. Hydrothermal alteration is common in Datil volcanics near cauldrons and the GRA is assigned a moderate favorability (3) at a confidence level of C.

   The Veranito and Sierra las Canas WSAs contain Datil volcanics, but there are no known occurrences of kaolin. It is assigned a low favorability (2) at a confidence level of B. The Stallion WSA contains no Tertiary volcanics and is considered not favorable (1) at a confidence level of D.

Oil and Gas

Two oil exploration wells have been drilled within the GRA and both were dry. Paleozoic formations present within the area include adequate source and reservoir rocks, but the intense faulting precludes entrapment of significant oil or gas at least in the western two thirds of the GRA. The GRA and the three WSAs are assigned a low favorability (2) at a confidence level of C.

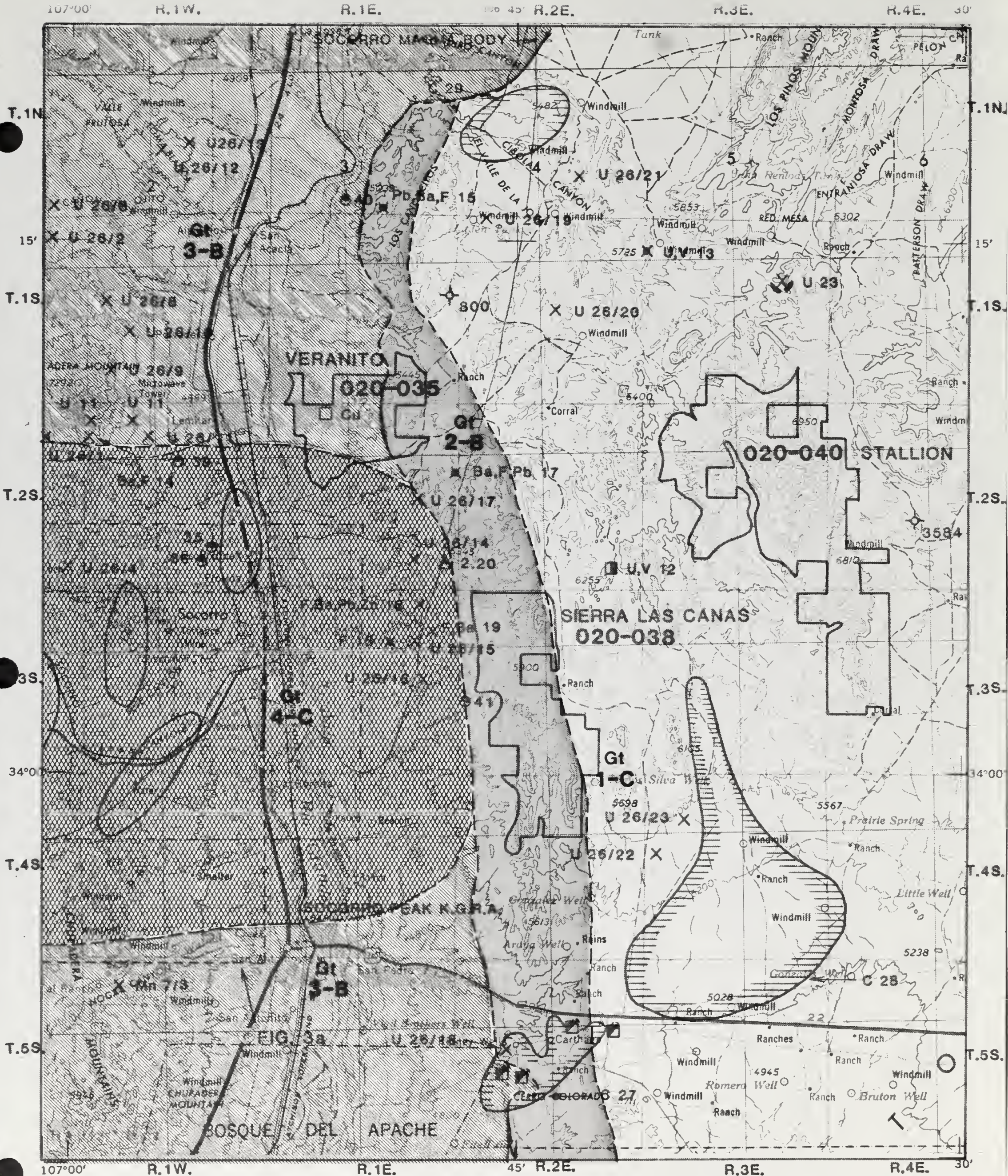


FIG.7 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR GEOTHERMAL RESOURCES OF THE SOCORRO AREA, NEW MEXICO.

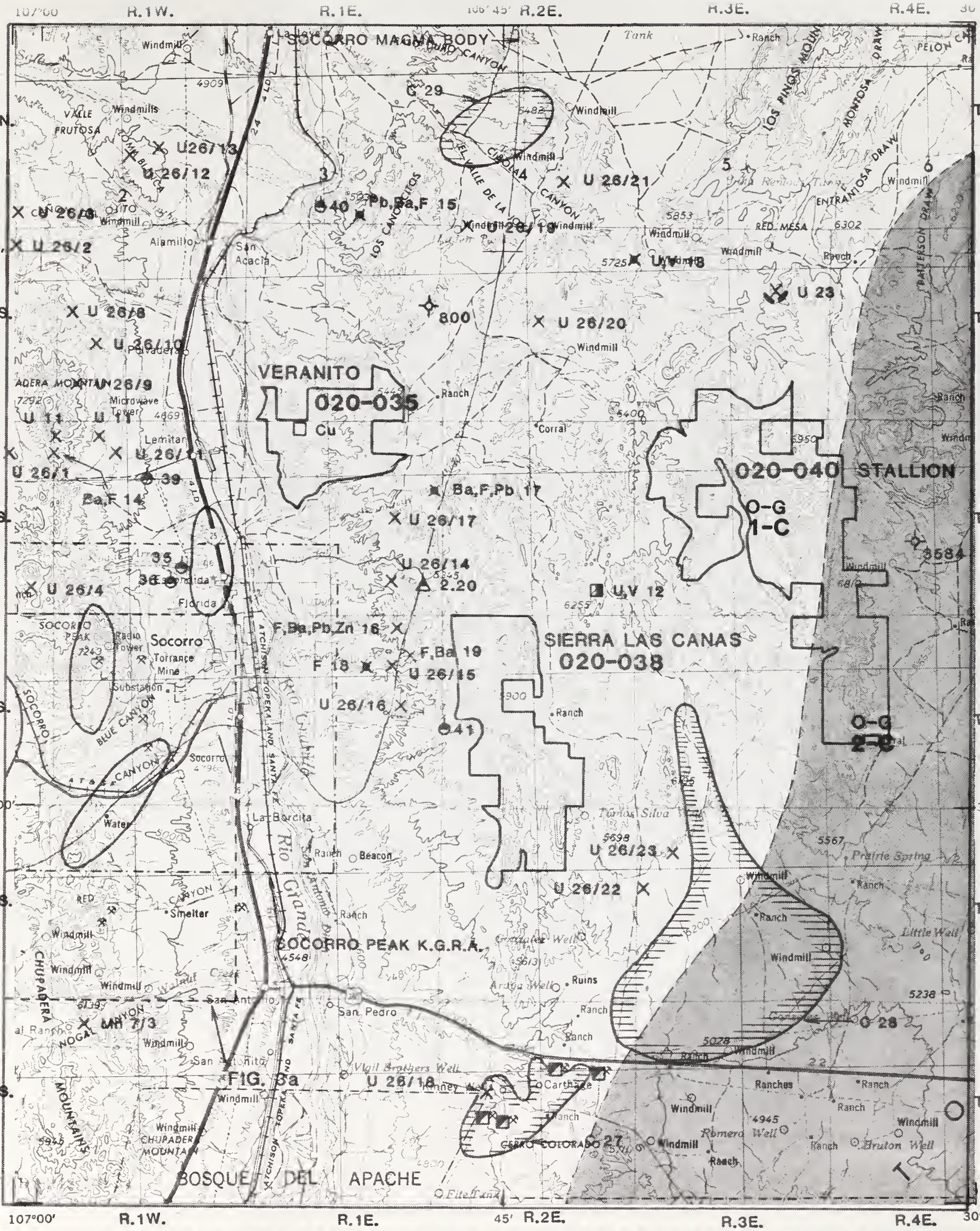


FIG.8 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR OIL AND GAS RESOURCES OF THE SOCORRO AREA, NEW MEXICO.

Geothermal

In the Socorro area the presence of numerous hot springs, high heat flow, steep geothermal gradients and geophysical evidence for shallow magma chambers show that an adequate heat source underlies the area. Furthermore, the presence of rocks with high primary and secondary permeability and of impermeable cap rocks suggest that significant volumes of hot fluids may be trapped beneath the ground. Thus, the GRA is assigned to a high favorabilty class (4) at a confidence level of C.

The Veranito WSA is close to one of the shallow magma chambers and probably overlies permeable reservoirs and impermeable cap rocks. It is assigned to a high favorability class (4) at a confidence level of B. The Sierra las Canas WSA lies along the faulted margin of the Rio Grande rift and is about six miles from one of the shallow magma chambers. It probably is underlain by rocks with secondary permeability, but it is not known whether cap rocks are present. A warm spring is present near its western boundary and the WSA is assigned a moderate favorability class (3) at a confidence level of B. There is no evidence of geothermal activity beneath the Stallion WSA and it is assigned to an unfavorable class (1) at a confidence level of C.

Gypsum

Gypsum-rich sediments occur in the Torres member of the Yeso Formation, although they are unlikely to be economic because of the availability of more pure deposits in playa lakes and dune sands in other parts of central New Mexico. The GRA is assigned a low favorability (2) at a confidence level of C. The Yeso Formation does not crop out in the Veranito WSA which is assigned to an unfavorable class (1) at a confidence level of D. The Stallion and Sierra las Canas WSAs are partly underlain by the Yeso and are assigned a low favorability (2) at a confidence level of C.

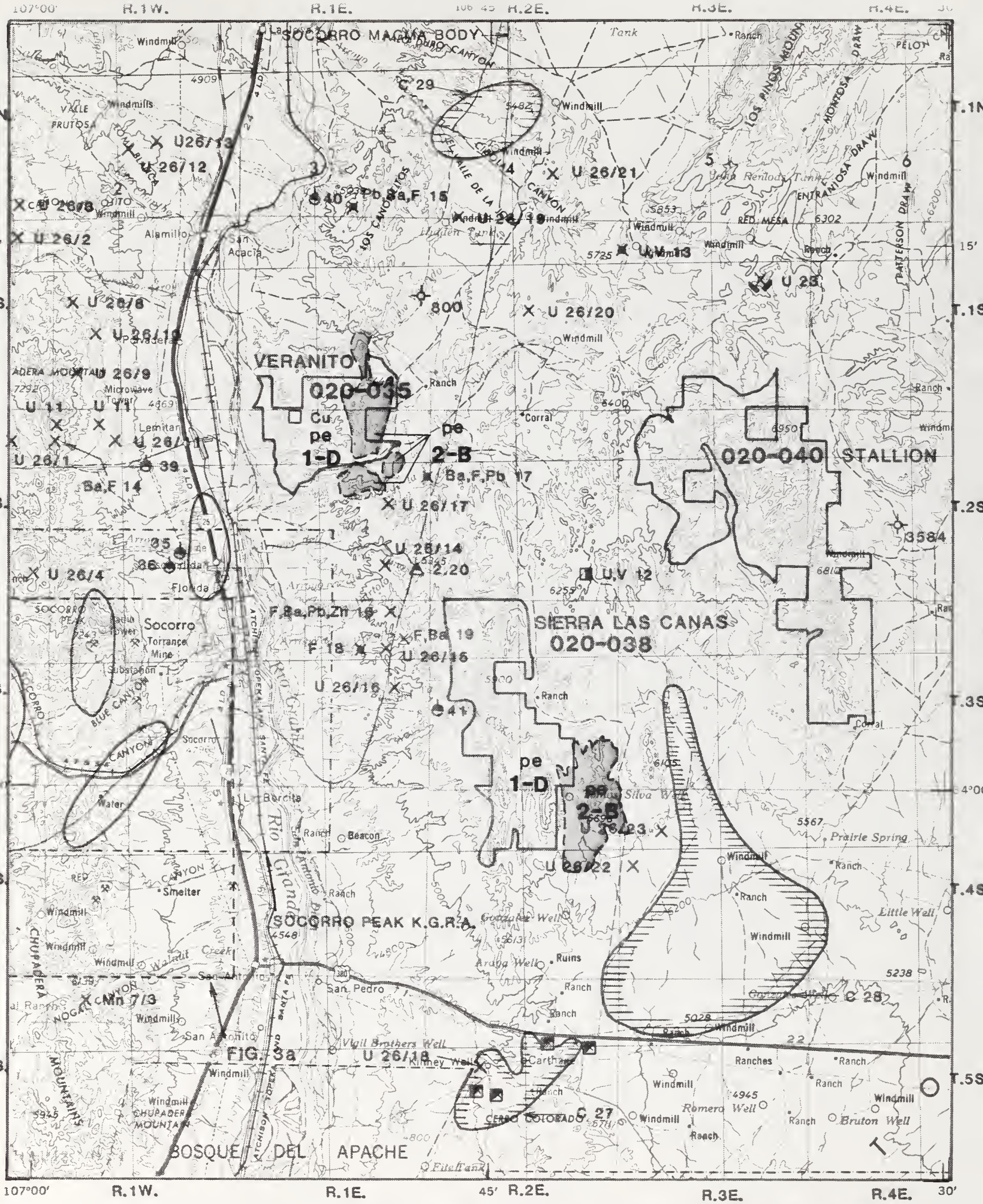


FIG. 9 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR PERLITE RESOURCES OF THE SOCORRO AREA, NEW MEXICO.

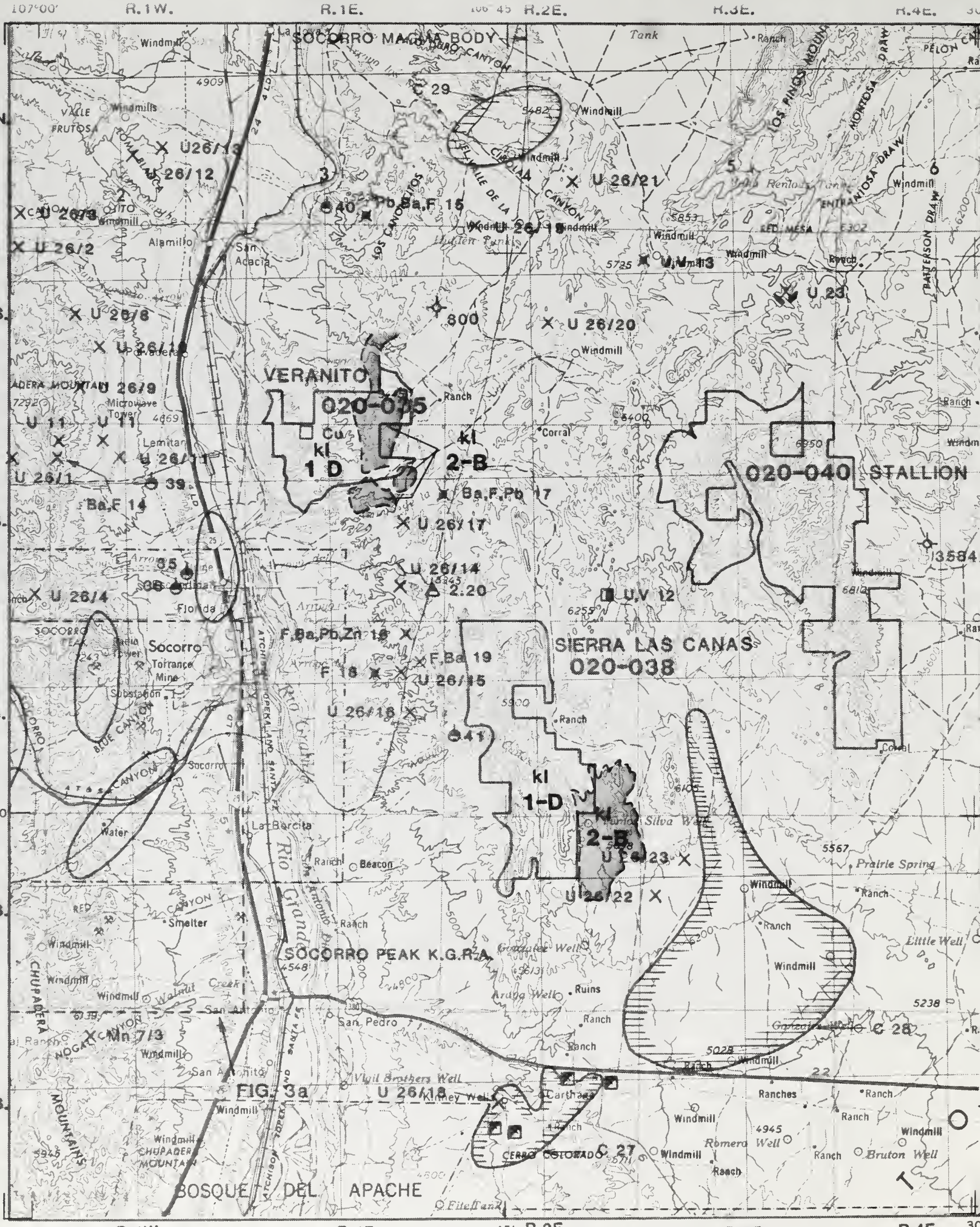


FIG.10 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR HYDROTHERMAL KAOLIN RESOURCES OF THE SOCORRO AREA, NEW MEXICO.

Coal

A four- to seven-foot thick coal seam extends under a ten square mile area in the Carthage field and thinner beds underlie the Jornada del Muerto field. Readily strippable coal has been removed and the coal beds are folded and faulted, increasing the difficulty of underground extraction. The coal could undoubtedly be mined in the case of an energy crisis. The GRA is assigned a moderate favorability (3) at a confidence level of C. The three WSAs are not underlain by coal beds and are assigned to an unfavorable class (1) at a confidence level of D.

Crushed Rock

Quaternary basalt and Oligocene rhyolite are found in the GRA and could be used for crushed rock in the local construction industry. The GRA is assigned a moderate favorability (3) at a confidence level of D. The Veranito WSA is partly underlain by undifferentiated Datil volcanics and is assigned a low favorability (2) at a confidence level of C. No rhyolite or basalt crops out in the Stallion or Sierra las Canas WSAs and they are considered to be unfavorable (1) at a confidence level of D.

Sand and Gravel

Sand and gravel occur in the Popotosa and Santa Fe Formations and in Quaternary alluvium along the Rio Grande and could be useful in the local construction industry. The GRA is assigned a moderate favorability (3) at a confidence level of D. The Veranito WSA is partly underlain by the Santa Fe Formation and Quaternary alluvium and is assigned a moderate favorability (3) at a confidence level of C. The Stallion and Sierra las Canas WSAs are not underlain by sand and gravel deposits and are considered unfavorable (1) at a confidence level of D.

Limestone

The San Andres limestone is widespread in the GRA and it is probably of sufficient quality for common use. The GRA is assigned a moderate favorability (3) at a confidence level of C. No limestone crops out in the Veranito WSA and it is considered unfavorable (1) at a confidence level of D. The Stallion and Sierra las Canas WSAs are partly underlain by the San Andres limestone and are assigned a moderate favorability (3) at a confidence level of C.

Perlite

The Socorro perlite deposit lies in the Chupadera Mountains and contains large reserves of perlite. The GRA is assigned a high favorability (4) at a confidence level of D. The Veranito and Sierra las Canas WSAs are partly underlain by undifferentiated Datil volcanics and are assigned a low favorability (2) at a confidence level of B. No rhyolitic rocks crop out in the Stallion WSA and it is considered unfavorable (1) at a confidence level of D.

Bentonite

Bentonite is reported as beds in the Santa Fe Formation and might be used in drilling mud if a local market for it exists. The GRA is assigned a low favorability (2) at a confidence level of B. The Veranito WSA is partly underlain by the Santa Fe Formation and is assigned a low favorability (2) at a confidence level of B. The Stallion and Sierra las Canas WSAs do not contain Santa Fe outcrops and are considered unfavorable (1) at a confidence level of D.

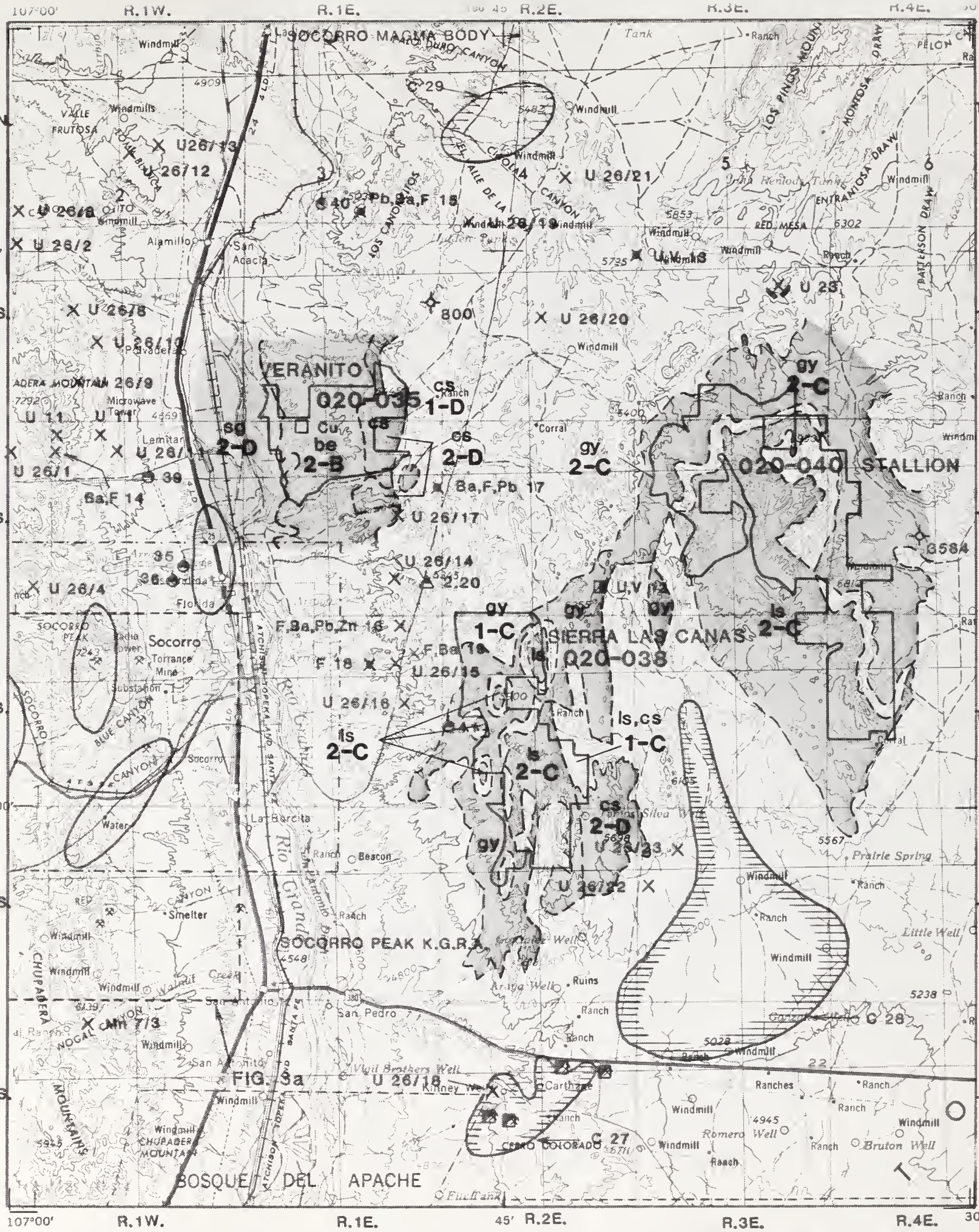


FIG.11 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR GYPSUM (gy), LIMESTONE (ls) AND CRUSHED ROCK (cs), BENTONITE (be), AND SAND GRAVEL (sg) RESOURCES OF THE SOCORRO AREA, NEW MEXICO.

RECOMMENDATIONS FOR ADDITIONAL WORK

The recommendations presented in this section pertain to the three WSAs within the Socorro GRA. They describe proposed work that would allow a more specific definition of mineral potential for various mineral deposit types for which the geologic environment appears favorable.

The Veranito WSA

This WSA contains undifferentiated Datil volcanics, Santa Fe Formation and Quaternary alluvium. The Datil volcanics could host structurally controlled hydrothermal deposits of precious and base metals possibly associated with cauldrons to the southwest; the Santa Fe Formation could host stratabound uranium deposits; placer gold deposits could be located in the alluvium; and the whole area could be underlain by a geothermal reservoir.

Hydrothermal Deposits

In order to assess the potential for hydrothermal deposits in the Datil volcanics, it is recommended that:

1. Datil volcanics should be examined in the field especially for evidence of intense and extensive hydrothermal alteration and evidence for the presence of low grade, possibly disseminated, gold silver mineralization. Such occurrences could have been missed during earlier prospecting in the Socorro area.
2. Selected samples should be studied petrographically to check the nature of hydrothermal alteration and to select possible samples for assay.

Stratabound Uranium Deposits

The Santa Fe Formation contains adequate uranium source rocks and is sufficiently permeable to allow groundwater circulation. However, it is not knwn whether suitable reductants are present. It is recommended, therefore, that:

1. The Santa Fe Formation, within and around the WSA, be checked for the presence of reductants such as organic matter.
2. The area can be checked for evidence of present or past hot spring activity that may have been sufficiently reducing to cause precipitation of uranium.
3. Furthermore, it is recommended that available wells be sampled and analysed for uranium, fluorite, phosphate, carbonate, calcium, potassium, vanadium, Eh and pH, and the solubility index be calculated for each sample. This would make it possible to determine whether uranium was being leached or precipitated within a given aquifer.

Placer Gold Deposits

The alluvium near the Rio Grande should be field checked for any evidence suggesting placer operation.

Geothermal Potential

The WSA should be field checked for evidence of recent hot spring activity.

The Sierra las Canas WSA

This WSA mainly contains outcroppings of Madera, Abo, Yeso and San Andres Formations and is intensely faulted. The Madera Formation could host structurally-controlled hydrothermal lead-zinc-barite-fluorite mineralization, the Abo and the Yeso could host stratabound copper, and the whole area could be underlain by a geothermal reservoir.

Hydrothermal Deposits

Small deposits of lead-barite-fluorite occur along faults to the west of the WSA. It is recommended that faults cutting the Madera Formation be field checked for the presence of hydrothermal deposits.

Stratabound Copper Deposits

Numerous occurrences of copper $\pm$ silver are located within Permian red-bed sediments in central and north-central New Mexico. Most occurrences are associated with local reducing conditions which caused precipitation. It is possible that copper and silver may also have been concentrated by a "sabkha"-type process, especially within the Yeso Formation. It is recommended that:

1. The Permian sediments be field checked for presence of locally reducing facies that may have acted as precipitants for copper and/or silver.
2. The Yeso Formation be field checked for "sabkha"-type environments where copper and silver may have been concentrated.
3. Furthermore, it is recommended that groundwater wells and springs be sampled and analyzed for copper, silver, chloride, reduced sulfur, carbonate, Eh and pH, and that the solubility index be calculated for each sample. This would make it possible to determine whether copper and silver were being leached or deposited within each aquifer sampled.

Geothermal Potential

The WSA should be field checked for evidence of recent hot spring activity.

The Stallion WSA

This WSA contains the Abo, Yeso and San Andres Formations and the Glorieta sandstone. The Abo and the Yeso Formations could host stratabound copper mineralization.

Numerous occurrences of copper $\pm$ silver are located with Permian redbeds in central and north-central New Mexico. Most occurrences are associated with local reducing conditions which caused precipitation. It is possible that copper and silver may also have been concentrated by a "sabkha"-type process, especially within the Yeso Formation. It is recommended that:

1. Permian sediments be field checked for the presence of locally reducing facies that may have acted as precipitants for copper and/or silver.
2. The Yeso Formation be field checked for "sabkha"-type environments where copper and silver may have been concentrated.
3. Furthermore, it is recommended that groundwater wells and springs be sampled and analyzed for copper, silver, reduced sulfur, chloride, carbonate, Eh and pH, and that the solubility index be calculated for each sample. This would make it possible to determine whether copper and silver were being leached or precipitated within each aquifer sampled.

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